Report No. FAA-EE-78-26

LEVEL II

PROCEEDINGS

AIR QUALITY AND AVIATION: AN INTERNATIONAL CONFERENCE

OCTOBER 16-18, 1973
Reston, Virginia

N. Sundararaman, Editor

U.S. DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
Office of Environment and Energy
Washington, D.C. 20591

(A)

Technical Report Documentation Page

(14) 1. Report No. FAA-EE-78-26	2. Government Accession No.	3. Recipient's Catalog No. (11)
(6) 4. Title and Subtitle: Proceedings, Air Quality and Aviation: An International Conference, 16-18 October 1978, Reston, Virginia		5. Report Date: November 1978 6. Performing Organization Code
(18) 7. Author(s): N. Sundararaman, Editor		8. Performing Organization Report No. FAA-EE-78-26
9. Performing Organization Name and Address: U.S. Department of Transportation, Federal Aviation Administration, Office of Environment and Energy, Washington, D.C. 20591		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address: Federal Aviation Administration, Office of Environment and Energy, 800 Independence Avenue, S.W., Washington, D.C. 20591 (12) 251 p.		13. Type of Report and Period Covered: Conference Proceedings, October 16-18, 1978 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This is the Proceedings of "Air Quality and Aviation: An International Conference" held in Reston, Virginia at the International Conference Center, from October 16-18, 1978. It includes 24 papers, a panel discussion, and edited question-and-answer exchanges following most of the papers.

17. Key Words	18. Distribution Statement
Emissions from aviation-related sources Impact of aircraft emissions on ambient air quality Air pollution	Document is available through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

What are the effects of aircraft operations on ambient air quality? It has been becoming increasingly apparent that the scales to be considered range from local to regional and that aircraft as a source of emissions have to be distinguished from other airport-related sources such as passenger and ground support vehicles, and stored fuel.

To evaluate the state-of-the-art of the impact of aircraft engine emissions on air quality, the Federal Aviation Administration hosted an International Conference on Air Quality and Aviation during October 16-18, 1978, at Reston, Virginia. The Conference was co-sponsored by the U.S. Air Force, the Air Pollution Control Association, and the U.S. Environmental Protection Agency.

This volume is the Proceedings of the Conference. The twenty-four papers presented were divided into sessions on Air Quality and Emissions Standards -- General Airport Sources and Emissions Data Base, Air Quality Modeling, and Case Studies. The concluding session was a Panel Discussion on "Where do we go from here?" A keynote speech on aircraft emissions and air quality was delivered by Mr. Ernest Rosenberg of the U.S. Environmental Protection Agency.

Even though not directly related to the subject matter, a highlight of the Conference was the Federal Aviation Administration Extraordinary Service Award made to Air Commodore Sir Frank Whittle, K.B.E., C.B., F.R.S., in recognition of his pioneering efforts in developing the turbojet engine in the 30's and 40's. A summary of Sir Frank's invited speech at the special luncheon is included.

The technical findings of the Conference on the pollutants of interest in a subject area still in the throes of evolution, can be summarized as:

(1) Hydrocarbons (HC): In view of the complex nature of the relationship between HC and the photochemical oxidant problem, it appears that aircraft as a source cannot be considered in isolation. They must be viewed along with other sources in the region;

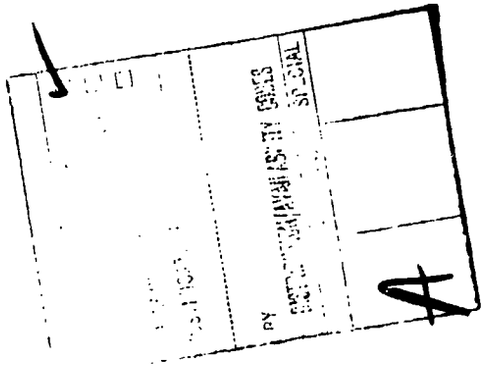
(2) Carbon Monoxide (CO): General aviation aircraft appear to make little contribution. With regard to other aircraft, periods and areas of intense activity (ramp and queuing areas, automobile access roadways, vicinity of buildings and terminals) may give rise to "hot" spots.

3) Nitrogen Oxides (NO_x): The NO_x is emitted as nitric oxide (NO) along the runway. The problem may be quite local and its severity appears to be linked to the levels of ozone in the airport vicinity;

(4) Particles: Particle emissions do not appear to be a problem except for possible effects on visibility around airports.

I take this opportunity to acknowledge the debt I owe to J. Stuart Jamison (Federal Aviation Administration), David L. Henderson, Harvey Kinston, M. Stuart Kreischer, David Sargent, and James D. Spart (Office of the Secretary of Transportation), without whose valuable, uncomplaining and unstinted help the Conference would never have taken place.

I owe special thanks to Charles Jones of the Federal Aviation Administration for his cheerful readiness to execute whatever foul task I set him to; and my deepest gratitude goes to Florence M. Ormond of ORI, Inc., without whose technical competence and unfailing assistance the Conference would never have been the success it was.



N. Sundararaman
Editor

PROCEEDINGS
AIR QUALITY AND AVIATION: AN INTERNATIONAL CONFERENCE
OCTOBER 16-18, 1978
Reston, Virginia

CONFERENCE CO-CHAIRMEN:
Charles R. Foster
John E. Wesler
Office of Environment and Energy
Federal Aviation Administration

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

WELCOMING REMARKS

John E. Wesler, Conference Co-Chairman
Office of Environment and Energy
Federal Aviation Administration

Good morning, ladies and gentlemen. It is my pleasure to welcome you this morning to the first day of a three-day conference on Air Quality and Aviation: An International Conference.

My name is John Wesler. I am the Acting Director of Environment and Energy of the Federal Aviation Administration in Washington.

And on behalf of the FAA, the Environmental Protection Agency, the Department of the Air Force, the Air Pollution Control Association, and the Society of Automotive Engineers, I would like to welcome you.

All five agencies are jointly sponsoring our conference this morning. As the title of our conference indicates, our theme is the relationship between air quality and aviation.

Our purpose here during these three days is to examine aircraft as a source of air contaminants and to examine airports as a location of that pollution in relation to the air quality, in general, and to its effect on the public health and welfare, in particular.

Thus, in effect, we are here to examine the state of our knowledge of aviation and its effects on the air quality.

This is not just an idle academic exercise for us. Under the law, as I am sure you know, the Environmental Protection Agency is responsible for setting emission standards for aircraft engines, and the Federal Aviation Administration is responsible for enforcing those standards.

We have a joint interest in deciding what is known and what is not known about aircraft emissions and their effect on air quality.

As I am sure you know, last March EPA announced its intention to reexamine aircraft emission standards, which they originally issued in 1973. Our three days here are to help in that reexamination by EPA and the FAA together.

We also feel we are trying to carry out President Carter's policy on Federal regulations, which he issued some time ago. Very quickly, he has directed Federal agencies to make certain that any regulations they issue are simple and clear, achieve legislative goals effectively and efficiently, and do not impose an unnecessary burden on any group--industry, the public, consumers, any group at all.

During the three conference days we look to you to help us to do that. We look forward to your expert guidance.

We ask you to pay special attention throughout the conference because Wednesday afternoon during the panel discussion we will have a test for you.

Our chairman this morning is George Kittredge. As I am sure you know, Mr. Kittredge is Senior Technical Advisor in the EPA's Office of Mobile Source Pollution Control.

AIR QUALITY AND EMISSION STANDARDS - GENERAL

Chairman: G. D. Kittredge
Environmental Protection Agency

MEASUREMENT AND ANALYSIS OF AIRPORT EMISSIONS

Major Peter S. Daley, Detachment 1, Armament Development Test Center
United States Air Force, Tyndall AFB, Florida

Major Dennis F. Naugle, Dept of Environmental Sciences and Engineering
University of North Carolina, Chapel Hill, North Carolina

ABSTRACT

This paper is of interest to those involved in regulation and analysis of aircraft related air pollution problems. USAF efforts to measure and model airport pollution are summarized. Efforts include: (1) a joint EPA study at Williams AFB, AZ which involves both modeling and measurement, (2) photographic studies to track plume rise, (3) theoretical modeling studies to analyze airport pollution. The author concludes that the Williams study, soon to be completed, will greatly aid in determining the accuracy of airport air pollution dispersion models, that air quality modeling studies have shown that state-of-the-art Air Force engines cannot be cost effectively modified to reduce pollution except possibly in the hydrocarbon area and that, at present, unpredictable thermal plume rise of aircraft exhausts renders model ineffective at locations close (<1 km) to the source.

INTRODUCTION

The issue of airport pollution is of great concern to the international aviation community. Today we stand at a decision point critical to this issue. The direction we take could have a major effect on engine designs and costs. The decision is not an easy one. Data collected through extensive airport pollution measurement programs have not clearly demonstrated the influence of airports on the environment. Although air pollution dispersion modeling studies have not been fully accepted as predictors of airport air quality, many have indicated a small impact for most pollutants. Reviews of both measurement and modeling have been published. In March of this year, the United States Environmental Protection Agency published a comprehensive review of past work to assess the air quality impact of a commercial aircraft (Reference 1). A 1975 Federal Aviation Administration review of modeling assessment techniques presents a comprehensive look at all but the most recent developments in airport air quality modeling (Reference 2). These studies have outlined strengths and shortcomings of both measurement and modeling techniques. The following discussion will briefly address some of of the issues identified in these reports and review several Air Force programs which are dedicated to resolving the outstanding problems.

MEASUREMENT PROGRAMS

Major airport air quality measurement programs have been conducted at several sites since passage of the 1970 Air Pollution Control Act. These have generally been conducted in conjunction with computer modeling studies in an attempt to verify modeling techniques. The studies have all suffered from the inability to clearly separate the airport and background urban pollution components. For this reason the US Navy, Environmental Protection Agency and Air Force joined together to measure and model pollution at an active military air base located far enough from urban centers so that the urban plumes would not obscure aircraft emissions. The base chosen was Williams AFB, Arizona, 40 miles east of Phoenix. Table 1 compares Williams operational frequency and emissions with Chicago O'Hare and Pittsburgh airports. The high activity level at Williams is due to its mission as a major pilot training base. The primary aircraft operated there are the T-37 and T-38 trainers powered by J-69 and J-85 engines, respectively. Both engines antedate any pollution control efforts, and the latter is a particularly large carbon monoxide emitter. Aircraft at Williams account for approximately 60 percent of the carbon monoxide atmospheric concentration in the vicinity of the base. Because of these high carbon monoxide emissions and its relative ease of measurement, carbon monoxide was the best pollutant choice for emission tracking in this study.

The field phase of the study lasted thirteen months and cost approximately $870,000. Table 2 delineates the instrumentation used in the study. Five complete air sampling and meteorological stations were assembled and sited as shown in Figure 1. Data were collected continuously by a minicomputer connected by telephone lines to each station. Final data reduction was accomplished under an Environmental Protection Agency (Las Vegas Environmental Research Center) contract. As is typical of all ambient measuring studies, instrumentation operation was not faultless. Valid data were recovered for more than 70 percent of our operating time; this compares favorably with Environmental Protection Agency (EPA) experience operating similar stations. The EPA does not compile annual averages from stations with data

recovery rates of less than 70 percent. Figure 2 is a typical graphical display of the preliminary results for one month of carbon monoxide sampling at one station. One hour average concentrations and other results were computed from one minute samples. Preliminary results indicate that the base had a relatively small influence on air quality. All one-hour carbon monoxide readings were less than one-half the National Ambient Air Quality Standard (NAAQS). The mean one-hour carbon monoxide level for all stations was less than one-eighth of the one-hour NAAQS. The annual mean nitrogen oxide concentration was less than one-fourth of NAAQS which is also an annual mean. The results indicate some short term hydrocarbon excursions due to aircraft operations, but the entire base contributes less than one percent of the combined hydrocarbon emissions for the base and its immediate environs.

One of the questions that has continually plagued measurement programs is whether or not the exhaust plume passes over the monitoring station undetected due to plume rise. The Air Force and the Federal Aviation Administration have addressed this question in two complementary studies, an in-house AF effort in which smoke traced plumes were tracked photographically (Reference 3) and a joint Air Force Federal Aviation Administration study in which carbon monoxide concentrations were measured at various heights as plumes passed 25 meter towers. The final report from the latter study is now being prepared. Figure 3 shows graphical traces of typical plumes photographically tracked. It is clear from these traces that ground separation can and does occasionally occur. The same conclusion was drawn from the tower studies. Ground separation occurs under unstable atmospheres with low winds. The conclusion to be drawn from this experience is that if ground measurement stations are to be sure to record aircraft plumes, they must be far enough from the source to assure that the plume has time to diffuse to the ground. This distance is probably of the order of one kilometer under worst conditions.

MODELING

The Air Force began its air base ambient air quality modeling program in 1972 with the adaption of the existing Airport Vicinity Model, developed by Argonne National Laboratory for the Federal Aviation Administration, to military flying operations. The resulting model, called the Air Quality Assessment Model (AQAM) and also developed at Argonne, is one of the most comprehensive air quality models available. It provides for up to fifty aircraft types and a complete array of mobile and stationary ground sources. It uses Gaussian point, line and area source dispersion equations to compute the concentrations of the five principal pollutants (SO_x, NO_x, hydrocarbons, carbon monoxide, and particulate matter) at up to 389 points. This array can then be used to plot concentration contours; Figure 4 is an example of nitrogen oxide isopleths. Hourly concentration predictions can be made for any given set of meteorological conditions or an entire year through the use of a meteorological subroutine.

The AQAM was used to evaluate the impact of AF flying operations on air quality (References 4, 5) and to evaluate the air pollution benefit obtainable by reducing emissions of state-of-the-art engines to established Air Force emission goals (Reference 7). To put the different pollutants in perspective in these studies, all concentrations were reduced to PSIs, the EPA Pollution Standards Index (Reference 6). Since PSI equivalents were not available for nitrogen oxides or hydrocarbons, the California one-hour NO_x standard of 470 $\mu g/m^3$ and the National Ambient Air Quality (3 hour) Hydrocarbon Standard of 160 $\mu g/m^3$ were arbitrarily set to a PSI of one-hundred with linear interpolation between zero and one-hundred.

The A-10 and F-15 aircraft were selected as typical state-of-the-art aircraft in the emission goals study. The A-10 is powered by two General Electric TF 34-100 engines and the F-15 by two Pratt and Whitney F-100 engines. The former is an advanced version of the older TF-34 turbofan series, and the latter is the Air Force's most recently developed production turbofan engine and powers the F-16 in addition to the F-15.

Plotted in Figure 5 are "worst cases" (1 m/s tail wind, "F" stability, and 115 m mixing depth) for positions 5 and 10 km downwind along the runway centerline. The solid symbols represent emissions from current engines and the dotted symbols, the PSIs that would be predicted if the AF were to retrofit the engines to meet the USAF Turbine Engine Emission Goals (Reference 7). The goals cannot be compared easily with the recently proposed revisions to commercial aircraft engine emission standards (Reference 8) because the latter assume a specific landing-takeoff cycle whereas the former are based on engine efficiency (CO and HCs) and combustor temperature (NO_x). The goals, when applied to typical A-10 and F-15 operations, will comply with the EPA standards for smoke and NO_x but not those for hydrocarbons and carbon monoxide. Future revisions of the goals will probably make them more restrictive for these latter two pollutants, however. Returning to Figure 5, it is clear that the only significant improvement to be obtained through application of the goals is in the area of reactive hydrocarbon (RHC) control. For SO_2 there is no goal, and TSP (total suspended particulate matter) and CO emissions are already so low that their contributions tc air pollution are inconsequential. For nigrogen oxides, the contribution to air pollution for the F-15 aircraft is relatively high; but the improvement obtainable through achieving the goals is small. It is interesting to note that the nitrogen oxide air pollution contribution for the F-15 aircraft is essentially the same as that of the much older F-4 it replaces in spite of the much higher F-100 engine pressure ratio. This is because the higher NO_x emission factors (mass of pollutant per unit mass of fuel) is compensated by the greatly improved performance (shorter time on take-off roll and climb out) of the F-15. Note that no improvement in hydrocarbon emissions is shown for the F-15 because the present engine meets the goals. The

earlier conclusion regarding the dominant importance of hydrocarbon emissions is the most important conclusion coming from this study; it is reinforced by our earlier work using AQAM to analyze the emissions of 10 bases (Reference 4).

The foregoing serves to point out the great value of dispersion modeling in airport pollution analysis. Only through modeling or extremely costly measurement programs could the inconsequential impact of the increased F-15 nitrogen oxide emissions be demonstrated. Nonetheless, modeling suffers a number of shortcomings. Perhaps the most often cited problem is that no airport model has yet demonstrated its accuracy even though the basically empirical Gaussian models are generally accepted prediction techniques. As pointed out previously, the failure of earlier studies to define the accuracy of airport models stemmed primarily from the high urban background pollution conditions. Also, part of the problem was the difficulty in obtaining accurate operational data and correspondingly accurate meteorological and pollutant measurement data to assure that the accuracy being assessed was that of the model and not that of the field data collection. A major effort was made at Williams to assure that field data collection was not the limiting factor. Argonne National Laboratory is now in the process of comparing the extensive data collected during the Williams AFB test to predictions made using the AQAM.

Another problem with dispersion models is that they cannot accurately predict pollution concentrations near buildings and other obstructions. This is especially important in attempts to assess the environmental impact of carbon monoxide in the vicinity of air terminals. The plume rise observations discussed earlier aggravate the problem further since most existing aircraft models do not include plume rise computations. No reasonable solution to this problem exists, and measurement appears to be the only practical method to assess airport air pollution close to the terminal.

CONCLUSIONS

The Air Force is engaged in a variety of studies to aid in the assessment of the airport pollution problems. The Williams AFB pollution measurement and modeling study now being completed will provide the most extensive airport measurements not completely obscured by background pollution. Comparison of the results with dispersion modeling predictions will provide a valuable measure of the ability of Gaussian models to predict airport pollution.

The application of the Air Force Air Quality Assessment Model (AQAM) to the analysis of air base pollution has shown that the most beneficial air pollution control investment the Air Force can make is in the field of hydrocarbon emission control. The use of the Pollutant Standards Index (PSI) as a common base to compare predicted concentrations of various pollutants was instrumental in reaching this conclusion and could greatly facilitate analysis of the commercial aviation pollution problem.

The rise of a turbine engine plume due to thermal bouyancy can occasionally cause ground pollutant measurement stations close to the aircraft to completely miss a passing plume. This, together with the inability of Gaussian models to predict concentrations close to obstructions, precludes their applicability to pollution prediction in the vicinity of airport terminals.

REFERENCES

1. Lorang, Philip, "Review of Past Studies Addressing the Potential Impact of CO, HC, and NO_x Emissions from Commercial Aircraft on Air Quality," Technical Support Report for Regulatory Action AC 78-03, Office of Mobile Source Air Pollution Control, US Environmental Protection Agency, March 1978.

2. Haber, J. M., "A Survey of Computer Models for Predicting Air Pollution from Airports," Federal Aviation Administration Technical Report No. 1231-1, Washington D.C., 25 May 1975.

3. Music, Paul D., J. S. Hunt and D. F. Naugle, "Photographic Measurements of USAF Aircraft Plume Rise," CEEDO TR 77-57, USAF Civil and Environmental Development Office, Tyndall AFB FL, Nov 1977.

4. Naugle, D. F., B. C. Grems and P. S. Daley, "Air Quality Impact of Aircraft at Ten U.S. Air Force Bases," J. Air Pollution Control Ass., 28, No. 4, p. 370-373, April 1978.

5. Naugle, D. F., P. S. Daley and H. A. Scott, "Air Quality Analysis of F-15 and A-10 Aircraft Engine Modifications to Reduce Pollution, CEEDO TR-78-35, USAF Civil and Environmental Engineering Development Office, Tyndall AFB FL, June 1978.

6. "Guidelines for Public Reporting of Daily Air Quality - Pollutant Standards Index (PSI)," EPA-450/2-76-013, August 1976.

7. "Pollution Abatement and Environmental Quality," AF Regulation 19-1, United States Department of the Air Force, Washington, D.C., June 1978.

8. "EPA Proposed Revisions to Gaseous Emissions Rules for Aircraft and Aircraft Engines," Federal Register, 43FR12615, March 24, 1978.

9. Krull, Nicholas, Personnel Communication of Federal Aviation Administration Data for Calendar Year 1976, May 18, 1978.

This paper has been reviewed by Office of the Secretary of Defense and is approved for public release. (20 June 1978, #20, DFOISR/OASD/PA. SAF/OIS document 78-991.)

TABLE 1

ANNUAL OPERATIONS/EMISSIONS FOR AIRCRAFT OPERATIONS

	CO'H(9)	P(9)	WAFB
Landing and Takeoff Cycles, thousands	345	145	155
Emissions, Metric Tons			
Nitrogen Oxides	4138	883	120
Hydrocarbons	8674	863	1416
Carbon Monoxide	14009	262	4255

Legend:
CO'H - Chicago O'Hare
P - Pittsburgh
WAFB - Williams AFB

TABLE 2

WILLIAMS AFB FIELD STUDY

Parameter Measured	Method
NO, NO_x	Dual reaction chamber chemiluminescent analyzer
Total hydrocarbon, CH_4, and CO	Gas chromatograph with flame ionization detector
Nephelometric visible light scattering	Integrating nephelometer
Wind speed and wind direction	Propeller vane anemometer
*Mixing depth	Monastatic acousting sounder
*Isolation	Pyranometer
*Vertical winds	UVW propeller anemometer

*Measured at only one location

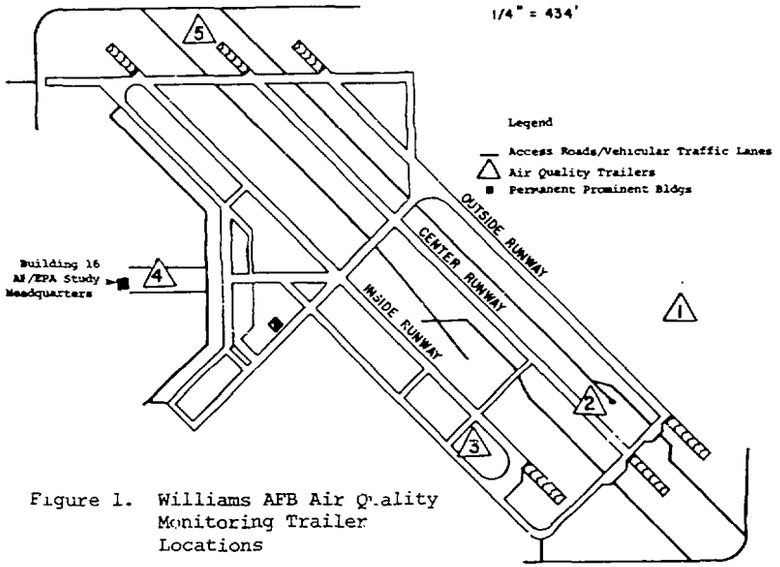


Figure 1. Williams AFB Air Quality Monitoring Trailer Locations

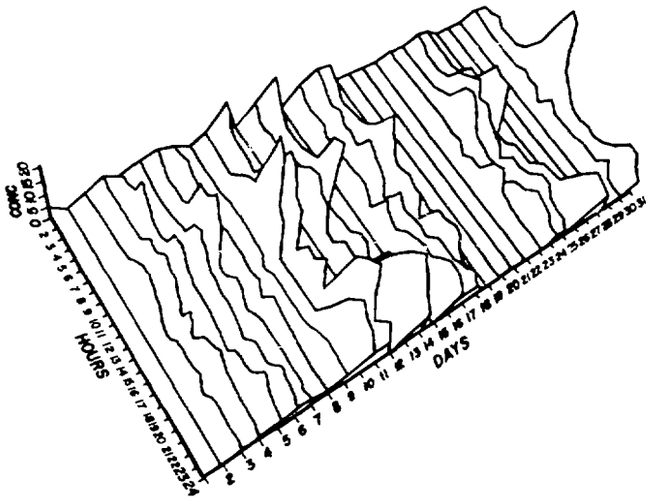


Figure 2. Typical Carbon Monoxide Concentrations for Station 4, January 1977

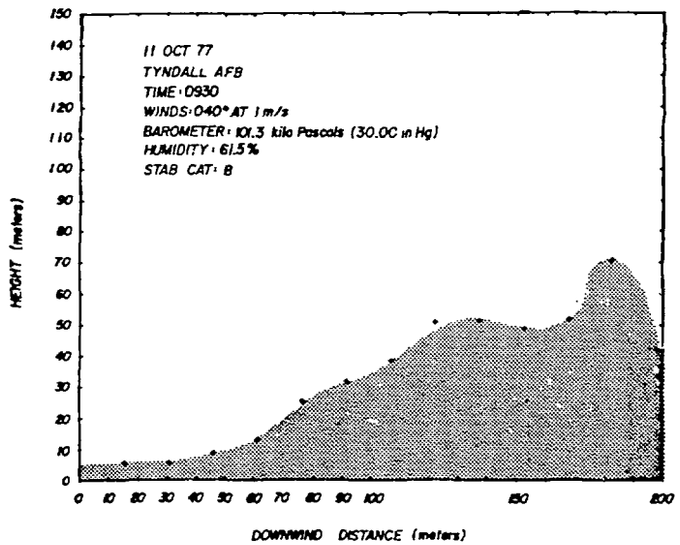


Figure 3. T-38 Aircraft Plume Traced Photographically

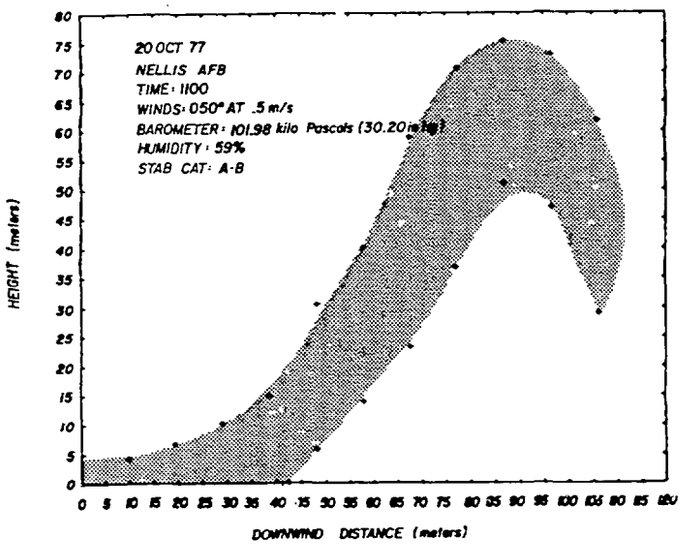


Figure 4. F-102 Aircraft Plume Traced Photographically

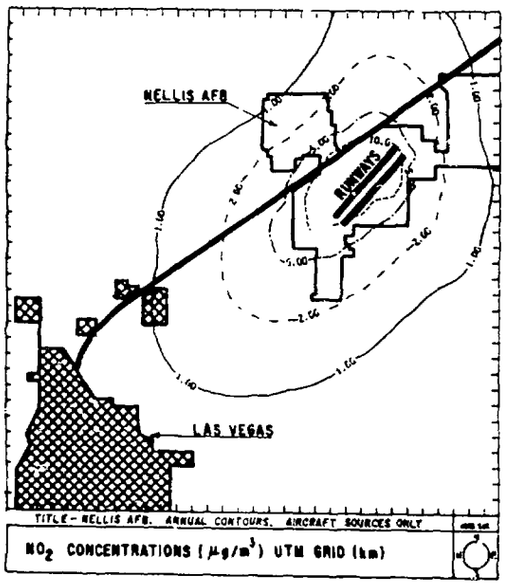


Figure 5. Nellis AFB Annual NO_x Concentrations

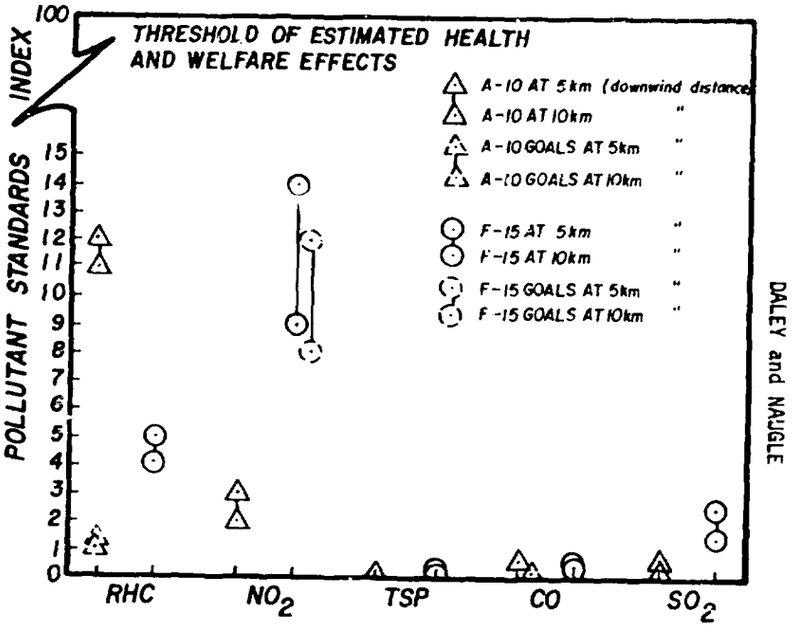


Figure 6. Changes in PSI Levels Through Application of USAF Emission Goals

DISCUSSION

KITTREDGE: Within EPA we are concerned over the relatively slower rate of progress in meeting the nationwide oxidant standard as opposed to some of the others, and this certainly has a bearing on our desire to achieve all possible control from relatively minor sources of hydrocarbons, such as aircraft.

DOWNIE: Did you measure the stability of the lower atmosphere? I didn't notice that in your meteorological findings.

NAUGLE: Are you referring to the plume rise experiments?

DOWNIE: Plume rise as well as any other.

NAUGLE: Yes, in both cases, a different type of yes. We collected the normal parameters and computed the Turner type A,B,C,D,E,F stabilities for plume rise, and we do have those available.

The looping plumes that you did see were stabilities A and B. Most of those were closer to neutral, a D-stability.

For the Williams ambient temperature projects we, of course, can and will compute Turner stabilities. We do have some ΔT measurements and some σ_θ measurements to use in deriving other types of stability information.

DOWNIE: In discussing Figure Two, which was a plot of the pollution versus time, I think, at Williams Air Force Base, you mentioned that the city was 40 miles away and you saw some effects in the evening. There was an evening maximum of some of the plumes. Was the transport of air mass right for this? Was there good correlation?

NAUGLE: No. It is perhaps due to the Phoenix basin. It is surrounded by mountains, and in the evenings there are often drainage winds off the mountains. Under these conditions we saw peaks. There was often a very low wind speed, and it was hard to determine any wind direction.

Many evenings it appeared the whole basin completely filled up, and, spatially, all places in the basin got high readings.

So, although we have looked and are still looking for those kinds of source-to-receptor wind directions, it becomes very complicated and, in general, is not a straight, easy-to-define function.

LEACH: Did you do any calibration of the plume rise to get some idea of whether the slope that you were using was indicative of the actual pollutants that we are interested in, such as NO_x, CO, and the hydrocarbons and much smaller particles?

NAUGLE: That is an obvious thing to do. We haven't as yet. The FAA has done some things like that in Dulles studies.

The Air Force has not, as yet, done that kind of calibration with these plume photographs. I hope we can. It is just something we haven't gotten to yet.

DALEY: I think if you will look at the particle size distribution and the particulate matter in the smoke you will find that it is extremely small and that any differential sett'ing you might get is inconsequential and that the plume does behave as a homogeneous mass of pollutants and particulate matter.

PASQUILL: The authors refer to the plume rise, and I wonder if they could say what, in their view, we have at present as a basis for generalizing about plume rise or, for that matter, whether anyone else in the audience can say.

The point is that there is a lot of theoretical work and verification experimental work on plume rise from power stations, for example, and one wonders to what extent one could immediately utilize some of the relations in those cases in order to at least estimate an order of magnitude in relation to the amount of heat emissions.

NAUGLE: This is a good question. There is certainly a lot of work to be done. We have not done it all, and I certainly would not claim we have.

I would say I am not quite sure how to answer that. We have related plume rises to a Holland-like equation. I am not sure if I fully understand the question.

PASQUILL: You partially answered it when you said you related it to a Holland equation. I thought you would have related it to a Briggs equation, which is buoyancy dominated.

NAUGLE: It appears that our plume is now also. I don't have any slides or results. We have done preliminary types of calculations, but I haven't in my own mind formulated any conclusions to give you an answer now.

It is certainly an area where your expertise could be helpful. Perhaps Argonne has something to contribute.

YAMARTINO: We have done some evaluations using the CO data that was taken with the tower array at Dulles Airport, and we have just submitted a paper to the AMS Reno Meeting on plume rise. We compare a best fit to the concentration profiles with what we get from a combination of a sort of Gaussian dispersion mechanism and a Briggs two-thirds-power-law rise.

We find that it is consistent with the two-thirds-power law and the magnitude of the rise is roughly about half of what you get if you just used the heat flux as you would compute it from the engine.

In other words, there is probably additional entrainment or something that is cutting the plume rise down to this factor of two below what you get from a straight Briggs calculation.

GOLDBERG: In your summation, you used NO_x and NO_2 interchangeably. Did you, in fact, measure both? In your computations did you assume that all the NO_x was NO_2 or did you, in fact, include the reactions that may take place?

NAUGLE: We did measure both at the Williams study. For the modeling exercises and, therefore, the last chart I showed you, we assumed that all NO has been converted to NO_2, because we know that most of the emission at the exit plane is in the NO form.

This is not necessarily a good assumption. It would be more in the order of a worst-case assumption. Any reactivity time constants would only

result in lowering the curve that you saw from the modeling experiment.

GOLDBERG: Did you see a big difference between your NO and NO_2 measurements?

NAUGLE: Yes. I am going through 13 months of data, and it is hard to get a definitive answer. On occasion, we saw big differences, but I don't know if we can draw general conclusions yet. Conclusions will be developed by Argonne.

LINDENHOFEN: You indicated that the biggest problem is hydrocarbons. Have you considered whether controlling hydrocarbons in the combustion process may cause CO levels to go up?

NAUGLE: Although there is a potential for that happening, in general, the control of hydrocarbons will lower CO. I know that is not always the case.

What we are suggesting is that the CO parameter is not a real significant parameter to be used as a constraint.

I would much rather, based on our modeling and measurement results, try to see that we lower hydrocarbons to the maximum degree. If CO increases, it has to increase many, many fold in order for there to be any significant environmental impact.

DALEY: I might add another comment on the CO problem. The environmental impact of CO as an ambient air pollutant has to be separated from the close-in impact of CO, which is an industrial hygiene problem for the people working in and around the aircraft. There are tremendous differences, both in the standards you are contending with and the levels obtained, when you get very close to aircraft operations. In our modeling operations we don't attempt to address that.

NAUGLE: There are differences between the Air Force's conclusions and what might be the civil airport conclusions.

KITTREDGE: This Air Force study has taken some four years, if I remember right, from gestation to now, and the information is going to be extremely timely, and certainly will be considered by us (EPA) with great seriousness in our move toward aircraft standards.

EMISSIONS OF OXIDES OF NITROGEN FROM AIRCRAFT

Bruce C. Jordan
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency

and

Anthony J. Broderick
Office of Environment and Energy
U.S. Department of Transporation
Federal Aviation Administration

ABSTRACT

Studies have been conducted to assess the adequacy of current aircraft emissions standards and to determine needs for future emission controls on commercial aircraft. A question of primary concern which has surfaced during these studies is the impact NO_x emissions from these aircraft have on ambient air quality. This paper has been prepared to outline what is presently known about NO_2 air quality impacts from commercial aircraft.

ON A NATIONWIDE BASIS, commercial aircraft contribute only a small percentage (less than 1%) to the total NO_x emissions. Even on a smaller geographical area basis, such as an air quality control region (AQCR), the contribution of NO_x emissions by aircraft to the total atmospheric loading in the area is generally less than 1%. Table 1 displays the aircraft contributions to total NO_x emissions in several AQCR's.

While the contribution by aircraft to total NO_x emissions over broad geographical areas is quite small, around major airports a somewhat different picture is found. Because of the high concentration of aircraft at such airports, NO_x emmission densities in the vicinity of the airport have been shown to be similar to emission densities in other portions of the urban area. Figure 1, which has been extracted from (1)*, provides an indication of how the NO_x emission densities at O'Hare International Airport compare with similar emission densities in the neighboring areas. For this reason, major airports have been frequently thought of as air pollution "hot spots."

Around a major airport such as O'Hare, NO_x emissions from commercial aircraft can exceed 3000 tons per year. Based on this emission rate and the emission densities, there is a tendency to conclude that aircraft are a major source of NO_x emissions and therefore should be controlled. However, emission inventories from aircraft are based upon a so

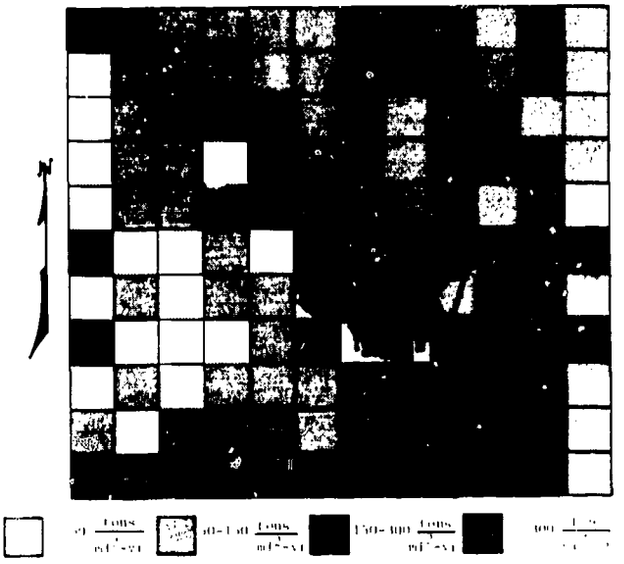


Fig. 1 - Nitrogen oxides emission densities from O'Hare Airport and the surrounding area

called landing and takeoff (LTO) cycle. Thus, the above emissions in reality include all aircraft operations from ground level to 3000 feet. Therefore, the inventory procedure actually includes emissions which occur both at high altitude and, generally, at some distance from the airport. For example, in a normal 3 degree approach, an aircraft flying at 3000 feet would be over 10 miles from the airport. Therefore, in order to obtain a more realistic assessment of the air quality impact from aircraft emissions, it is necessary to examine the various operational modes (such as landing, takeoff, taxi,

*Numbers in parentheses designate References at end of paper

Table 1 - Percentage of Total Emissions of Various Air Pollutants from Aircraft Operations

AQCR	Carbon Monixide		Hydrocarbons		Nitrogen Oxides		Particulates	
	All Aircraft	General Aviation	All Aircraft	General Aviation	All Aircraft	General Aviation	All Aircraft	General Aviation
Los Angeles	0.72%	0.30%	1.30%	0.20%	0.81%	0.07%	2.70%	0.33%
San Francisco	0.87%	0.39%	1.60%	0.30%	1.20%	0.10%	2.10%	0.47%
NY-NJ-Conn	0.44%	0.11%	0.70%	0.08%	0.50%	0.02%	0.27%	0.08%
Chicago	0.39%	0.07%	0.70%	0.05%	0.59%	0.06%	0.14%	0.02%
St. Louis	0.76%	0.11%	1.80%	0.07%	0.45%	0.01%	0.85%	0.03%
Cincinnati	0.11%	0.06%	0.40%	0.14%	0.30%	0.03%	0.05%	0.03%
Baltimore	0.59%	0.10%	0.80%	0.04%	0.73%	0.02%	0.87%	0.05%
Boston	0.58%	0.21%	0.84%	0.13%	0.71%	0.02%	0.67%	0.21%
Houston	1.15%	0.58%	0.80%	0.20%	0.65%	0.07%	1.30%	0.30%
S.E. Wisc.	0.37%	0.15%	0.30%	0.05%	0.40%	0.03%	0.12%	0.06%

etc.) undertaken by aircraft in the vicinity of the airport. Through such an examination, it has been found that nearly 90% of the hydrocarbon and carbon monoxide emitted during the landing and takeoff cycle occur during ground operations of the aircraft. However, because most NO_x emissions occur during high power settings, over 80% of the NO_x emissions occur during the approach, takeoff, and climbout modes of operation. Listed below are percentages of total aircraft emissions from the various modes of operation at a typical large airport (Hartsfield International Airport in Atlanta).

MODE	HC	CO	NO_x
Start up	22.3	13.5	1.3
Taxi out	27.2	23.7	3.5
Takeoff	0.2	1.4	21.9
Climbout	0.4	4.7	32.2
Approach	2.0	9.0	25.2
Landing	1.9	2.4	7.1
Taxi in	18.8	15.9	2.3
Shutdown	3.1	2.1	0.2
APU	0.3	2.6	3.6
Ground Serv	8.5	24.7	2.7
Fuel refill	15.4	-	-

From this list it can be seen that nearly 60% of the NO_x emissions occur during the approach and climbout modes and consequently in effect are emitted from a stack ranging from 0 to 3000 feet in height. For this reason it is not valid to make a one-to-one comparison of NO_x emissions from aircraft with those from other source categories. Likewise it is not valid to base the ground level NO_x emission density at an airport on emissions which occur during the total LTO cycle. Thus, to assess the air quality impacts of NO_x emissions from aircraft, it is necessary to model the various modes of operations and determine how they collectively impact on air quality.

REVIEW OF ANALYSIS USED AS BASIS FOR EXISTING NO_x STANDARDS

It appears that the primary basis for the existing aircraft emission standards are contained in a report prepared by the Environmental Protection Agency in 1972 (2). Briefly, for NO_x the analysis contained in this report consisted of mathematically modeling various modes of operation for aircraft at several large airports. The conclusion reached was that very high ground level concentrations of NO_x on the airport property resulted from aircraft operations. Also, it was concluded that aircraft operations could cause high concentrations of NO_x to be experienced in the residential and business areas surrounding the airport property.

Figures 2 and 3 are isopleths of annual NO_x concentrations in 1980 as the result of aircraft operations only as projected from the studies contained in (2). It should be noted that the isopleths are for NO_x, while the national ambient air quality standard is for NO_2 (annual average concentrations not to exceed 100 $\mu g/m^3$). Since most of the NO_x emissions from aircraft are in the form of NO, the NO_x concentrations shown do not necessarily represent expected NO_2 concentrations, but rather provide an approximation of the sum of the NO and NO_2 concentrations. The conversion of NO to NO_2 is a complex atmospheric chemistry process and was not addressed in the above study. Consequently, actual NO_2 concentration levels would be expected to be lower than the NO_x levels shown on the isopleths, unless the oxidation of the NO to NO_2 occurred very rapidly (see below).

The concentration levels of NO_x predicted in (2) are strongly dependent upon the emission factors used for the various operational modes. While modal emission factors are not presented in (2), yearly NO_x emissions from aircraft are given. These emissions are based upon the LTO cycle previously discussed. A more recent analysis of NO_x emissions from aircraft at several major airports is contained in (3). The latter study takes into account updated modal emission factors, mixture of different type aircraft operations at the airport and more recent projections of future aircraft activity at these airports. The results of this latter study indicate that projected NO_x emissions from aircraft may have been greatly overestimated in (2). Projected NO_x emissions from Los Angeles International Airport (LAX) and O'Hare Airport (ORD) from (2) and (3) are shown below:

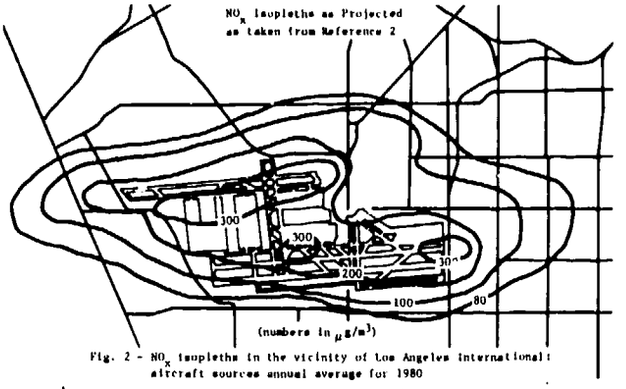


Fig. 2 - NO_x isopleths in the vicinity of Los Angeles International: aircraft sources annual average for 1980

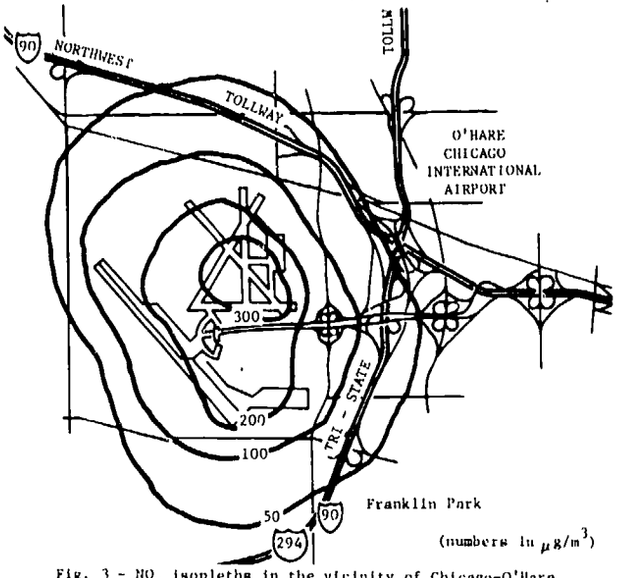


Fig. 3 - NO_x isopleths in the vicinity of Chicago-O'Hare International: aircraft sources annual average for 1980, as taken from reference 2

Airport	1980 NO_x Emissions from Airport	
	Reference 2	Reference 3
LAX	11,490	4,796
ORD	7,440	6,295

As can be seen, NO_x emission estimates appear to have been overestimated by a factor of 2.4 at LAX and 1.2 at ORD. There are probably several reasons for this apparent overestimation, including improper emission factor estimates, errors in the projected aircraft activity levels, and improper accounting for the different type aircraft expected to be operating at the various airports.

As previously mentioned, the mathematical model used in (2) did not consider the conversion of NO to NO_2. This was because of the absence of an adequate means to account for the conversion. Also the model was criticized because there was no apparent attempt to validate the results for NO_x.

NO-OXIDATION - The atmospheric conversion of NO to NO_2 is a very complex subject and beyond the scope of this paper. However, it is generally known that the rate at which NO is converted to NO_2 is dependent upon several parameters, including sunlight intensity, the rate at which the NO is mixed with the surrounding air, and the presence of ozone and other photochemical oxidants in the atmosphere. During a smoggy summer day, the conversion process may be very rapid and most of the NO could be oxidized in an hour or less. However, little oxidation of NO to NO_2 is expected to occur during the night hours and the rate of the conversion is thought to be considerably slower during the winter months than during the summer months. Consequently, annual average NO_x isopleths are probably not very representative of annual NO_2 levels, particularly those isopleths closest to the source of the NO_x emissions. For this reason and because of the overestimation of the NO_x emissions, the actual NO_2 concentrations caused by aircraft emissions would be expected to be considerably lower than the NO_x concentrations shown on the isopleth contained in (2).

For a brief discussion of the oxidation of NO, we set forth the following assumptions/constraints:

1. A reasonable range of probable values for a National Ambient Air Quality Standard for NO_2 is 0.25 to 0.5 ppmV (470 to 940 $\mu g/m^3$) one-hour average (8).
2. It is not possible to project achieving more than a 40 percent reduction in aircraft emission rates of NO_x, and such a reduction could not be realized prior to 2005, with a linear achievement of that reduction between 1985 and 2005 (i.e., 10 percent by 1990, 20 percent by 1995, etc. (7).
3. Though some small amount of aircraft NO_x emissions is in the form of NO_2, this amount is insignificant and will be ignored, since most of the NO_2 is emitted at idle/taxi power settings where NO_x emissions are almost negligible and NO-oxidation is fostered by a fuel-rich mixture.
4. The contribution of aircraft per se to local NO_x concentrations is 80 percent of the total NO_x concentration at any receptor near the airport: Table 11, (4).

Due to the rapidity of the dispersion process, NO_2 at the immediate airport site (which is caused by aircraft at that site) must arise from some rapid oxidation process. The predominant oxidation process for NO to NO_2 conversion in a typical urban atmosphere is:

$$NO + O_3 \longrightarrow NO_2 + NO_2 \qquad (1)$$

with a rate constant of about 27 $ppm^{-1}\ min^{-1}$.

In a photochemically active atmosphere, this reaction will proceed very rapidly, and we know of no others of practical importance in this case. In the absence of competing reactions, therefore, $NO_2 + O_3$ is a stoichiometric invariant. For our purposes, it is reasonable to assume the $NO + O_3$ reaction is instantaneous. On the other hand, O_3 replenishment reactions require much longer time (tens of minutes to hours) to be of significance. Thus, as the airport NO_x is dispersed, it consumes all the O_3 in the ever widening path of its plume until the plume NO_x concentration drops below the ambient oxidant level. At this point, there is more oxidant available than NO_x to consume it, and the $NO_x \rightarrow NO_2$ conversion in the plume is 100 percent. (Since it is not relevant to this discussion of short-term effects, we ignore subsequent photochemical ozone production owing to increased NO_2.) This phenomenon is well documented in the study of NO_2 production from power plant plumes.

For the purpose of this discussion, we initially draw on an idealized concentration-distance plot of a hypothetical airport's contribution of NO_x to the surrounding community (Figure 4). The local oxidant level controls NO oxidation on the short (less than ~1 hour) term, and the maximum amount of NO_2 which can be generated by this process is limited by the local ambient oxidant value. In the example shown in Figure 4, the airport NO_x varies from a hypothetical maximum of 0.23 ppmV about 0.12 km downwind of the airport, to very low (< 0.01 ppmV) levels beyond. However, assuming a maximum local oxidant level of 0.15 ppmV (dotted line), the near-airport NO_2 resulting from airport-NO oxidation is held to a maximum of 0.15 ppmV. Thus, the cross-hatched region shows a "cap" in the airport near-field, and 100 percent NO_2 yield from airport NO_x cannot be

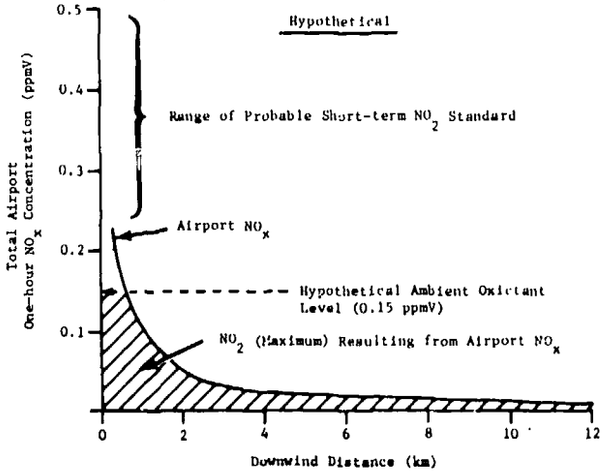


Fig. 4 - Relationship among airport NO_x, local oxidant and maximum airport-related NO_2, vs distance, for hypothetical case

obtained until local airport NO_x concentrations have been dispersed to at least the level of oxidant.

For illustrative purposes, Figure 5 schematically shows a highly simplified version of plume centerline concentrations of NO_x, NO, NO_2 and O_3 for a case where the exhaust-NO_x concentration (assumed to be initially 100 percent NO) is below that of the ambient O_3 level. Instantaneous initial plume-ambient air mixing is assumed to preserve ambient O_3 concentrations without diluting NO_x concentrations. The top sketch of Figure 5 shows the progress of dilution of NO_x as one moves further downstream of the exhaust exit. Note that, since the ambient O_3 amount was greater than the NO_x amount in the exhaust, all of the NO_x is assumed to be instantaneously converted to NO_2 (dotted line, top sketch) and no NO is present in the plume (center sketch). The behavior of O_3 in the plume is illustrated in the bottom sketch. Since, for this case, the initial exhaust NO_x concentration was about 75 percent of the ambient O_3 concentration, the plume-center O_3 is instantaneously reduced to about 25 percent of its initial value. The plume centerline O_3 recovers only in direct relation to the rate at which the plume centerline NO_x concentration is reduced by dilution.

Figure 6 shows similar sketches, except that in this case the exhaust plume initial NO_x concentration is assumed to be twice the ambient O_3 concentration. For this case, all of the ambient O_3 on the plume centerline is initially removed (bottom sketch), but this provides only sufficient oxidant to oxidize 50 percent of the plume-center NO. Thus, the initial plume center NO_2 concentration is 1.0 relative units (top sketch, dotted line), the other half of the plume-center NO_x being in the form of NO (center sketch) and the total NO_x is 2.0 units. As the plume-center NO_x is diluted downstream the NO_2 concentration remains constant at its maximum, and the only effect of dilution is to reduce the amount of NO at the plume center, until the total plume-center NO_x is diluted to the initial ambient ozone level of 1.0 units. From this point on, all the plume-center NO_x is in the form of NO_2, and the plume behaves like that shown in Figure 5. Thus, we have illustrated why one can place reasonable bounds on the short-term jet exhaust plume NO_2 levels: the maximum NO_2 concentration can be no greater than the ambient O_3 (oxidant) level.

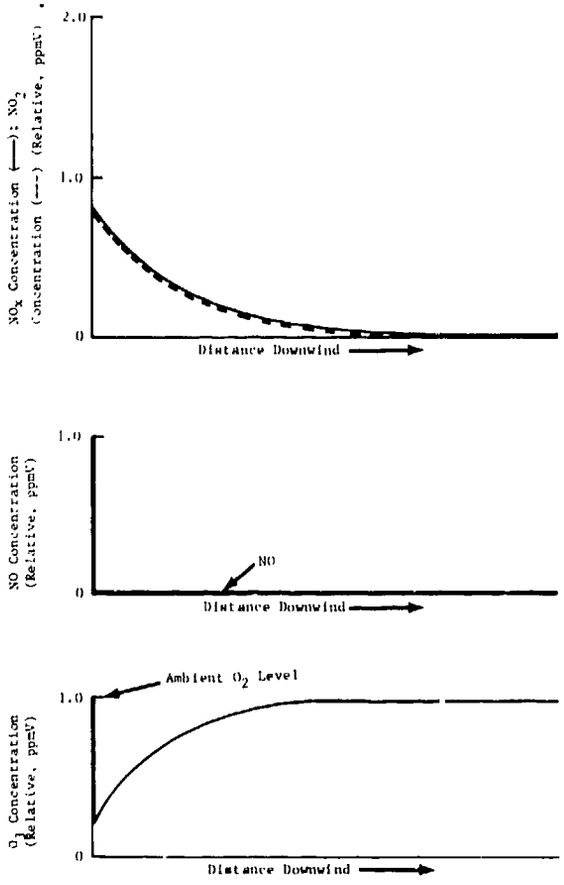


Fig. 5 - NO_x, NO, NO_2 and O_3 concentrations vs distance downwind (for initial NO_x < ambient O_3)

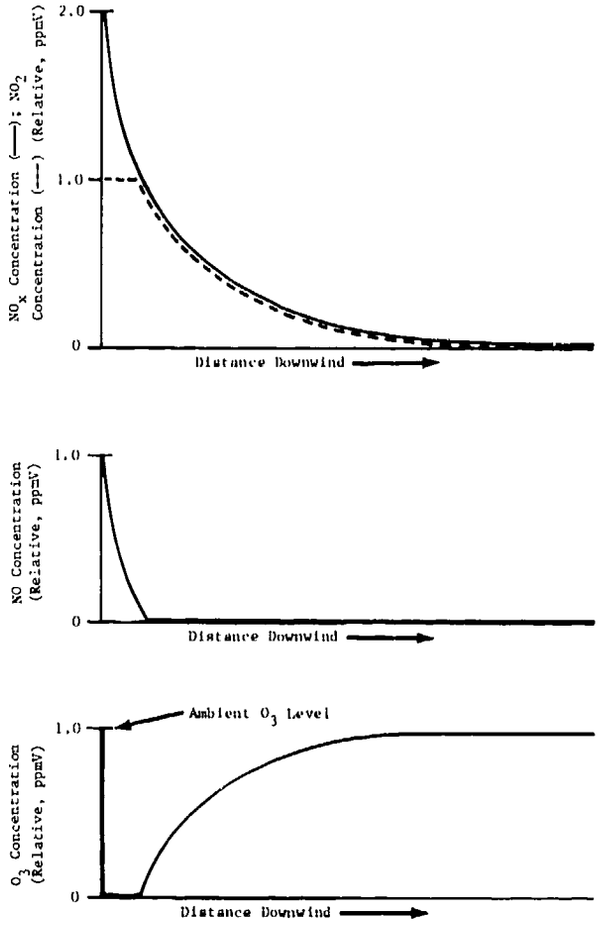


Fig. 6 - NO_x, NO, NO_2 and O_3 concentrations vs distance downwind (for initial NO_x > ambient O_3)

VALIDATION OF AIRPORT MODELS

In 1974 under the sponsorship of EPA, Geomet Incorporated undertook a study to validate mathematical models used to assess the air quality impacts of aircraft emissions. Ambient air monitoring that was collected at Washington National Airport over a six-month period (October 1972 to April 1973) was used in the Geomet study. This monitoring data indicated that high levels of NO_2 were being experienced at several points on the airport surface. Peak hourly concentrations of NO_2 in excess of 600 $\mu g/m^3$ were recorded at each of three monitoring locations on the airport property. The average of all recorded NO_2 levels during the six-month period was 180, 149, and 127 $\mu g/m^3$ at the three sites respectively. Thus, it appeared that there was a large potential for violations of the ambient NO_2 standard at each site. Unfortunately, the monitoring data alone does not differentiate between the NO_2 which resulted from aircraft emissions and that which resulted from other sources of NO_x.

During the Geomet study (4) it was found that the predicted NO_x concentrations at the monitoring site did not correlate very well with the measured NO_2 concentration. Generally, at each site the models tended to predict a higher NO_x concentration than the measured NO_2 levels. Depending upon the averaging time and the particular site, predicted NO_x concentrations ranged from 3 to 18 times the recorded NO_2. Over the six-month period, the average of all hourly NO_x concentrations predicted at the three sites was about eight times the actual measured NO_2 levels. The above results were obtained using one of the better airport models available.

The fact that the available models tend to predict higher NO_x concentrations on the airport surface than the recorded NO_2 is not surprising. The recorded NO_2 can result from NO emitted by sources on or near the airport which remain in the area sufficiently long to undergo the conversion process. Also, a portion of the recorded NO_2 can be the result of NO emitted at some distance from the airport which has had sufficient time to undergo the conversion before reaching the airport monitor.

Unfortunately, the study in (3) does not go into a detailed analysis of the monitoring data and therefore it would be somewhat speculative to attempt to draw conclusions. However, considering that the wind direction during the monitoring study was primarily out of the northwest, it would appear that NO_x emissions from the metropolitan D.C. area may have contributed substantially to recorded NO_2 levels.

The discussion in the preceding paragraphs becomes important because there has been a number of studies involving the impact of aircraft emissions on air quality. These studies have consistently shown that NO_x emissions from aircraft cause very high levels of NO_x concentrations at several points on the airport surface. However, as one moves away from the airport, these concentrations tend to drop off very rapidly, and except for a few major airports the NO_x concentrations caused by aircraft emissions appear to be very low at only a few kilometers beyond the airport property.

Given the rapid dispersion of the NO_x from aircraft, there is a potential that while pockets of high NO_x concentrations occur at local points on the airport surface, the NO_x is in the form of NO and is greatly dispersed before it would have sufficient time to be oxidized to NO_2. This would appear to be particularly true for long-term average concentrations such as for the current annual average NO_2 standard, which takes into account NO_2 average during both the summer and winter.

The fact that NO_x emissions from sources other than aircraft can strongly influence the measured NO_2 levels on the airport surface has been illustrated in several studies. Figure 7 shows the impact on predicted annual NO_x concentrations at several places on the Hartsfield International Airport in Atlanta, Georgia. The data on Figure 7 is divided into concentrations caused by airport sources, and that caused by nonairport sources. The airport sources include aircraft, ground service vehicles, heating plants, and airport access traffic. Note from Figure 7 that except near the end of one of the runways, and in the aircraft loading area (high concentrations of aircraft), nonairport sources contribute approximately two times more to the NO_x concentrations than do the airport sources. Even in the aircraft loading area where concentrations of aircraft are high, nonairport sources contribute about 50% to the predicted concentrations. The observations are for this particular airport because the prevailing winds tend to transport NO_x from the metropolitan Atlanta area and the interstate highway system which surrounds the airport.

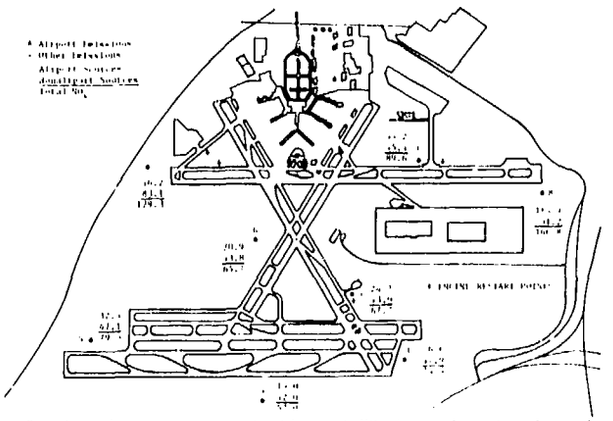


Fig. 7 - Annual average concentrations of NO_x from airport and nonairport sources at Hartsfield International Airport, Atlanta as taken from reference 5

This situation is not too unlike that previously noted for the Washington National Airport, and gives credence to the observations that the measured NO_2 at Washington National may have been strongly influenced by NO_x emissions from the metropolitan D.C. area.

IMPACT OF AIRCRAFT EMISSIONS ON SHORT-TERM NO_2 AIR QUALITY

While the available evidence indicates that the NO_x emissions from aircraft may have only a small impact on the NO_2 air quality from an annual average standpoint, the Clean Air Act Amendments require the EPA to determine if a short-term NO_2 standard is

needed. Therefore, it is prudent to examine what impacts such emissions may have on short-term NO concentrations. Also, while the time it takes to convert NO to NO_2 probably greatly reduces the impact of aircraft emissions on annual average NO_2 levels, this impact may be somewhat less for shorter averaging times. This is because over a given short period of time proper conditions for more rapid conversion exist than would be expected to occur on the average over a twelve-month period.

In March 1975 the Argonne National Laboratory completed a study in which one of the more modern airport models was used to study the effectiveness of various strategies for controlling aircraft emissions. In this study, which is contained in (5), Hartsfield International Airport was used as a representative major airport. Hartsfield is the second busiest commercial aviation airport in the country.

Figure 8 contains the predicted maximum one-hour average NO_x isopleths on the airport surface that would occur during the peak traffic conditions at Hartsfield Airport under normal operating conditions. Two situations are shown, one for the summer and one for the fall because of different meteorological conditions normally encountered during these time periods. The isopleths include estimated NO_x concentrations which would occur as the result of emissions from the airport sources (about 80% of which are aircraft), all point sources within a ten county area around the airport, and all area sources within 20 kilometers of the airport.

The isopleths in Figure 8 show there are relatively small pockets where the NO_x concentration can exceed 200 $\mu g/m^3$. Within these pockets there are isolated points where the projected concentration could reach 450 $\mu g/m^3$.

Although no national short-term NO_2 standard has yet been established, the World health Organization (WHO) has provided some recommendations for such a standard. The range of the WHO recommended standards are 190 to 320 $\mu g/m^3$ hourly average not to be exceeded more than once per month. Even with an instantaneous 100% conversion of the NO to NO_2, a person would have to remain within a relatively small area at the Hartsfield Airport for more than one hour to be exposed to NO_2 levels in excess of the lowest of the WHO recommended short standards.

The Argonne study also investigated a hypothetical worst case situation which included a very low speed wind directed such that the emissions from the metropolitan Atlanta area were advected onto the airport, a very low mixing height, Class 5 atmospheric stability, and ground operating conditions such that aircraft queue lengths (such as waiting for departure) were four times above normal.

The results of the modeling for the worst case condition is shown on Figure 9. This figure implies that under very unusual circumstances the airport could experience pockets of hourly average NO_x concentrations in excess of 550 $\mu g/m^3$. Within these pockets there are locations where the one-hour average NO_x concentrations can reach 900 $\mu g/m^3$.

The Argonne study did not differentiate between airport and nonairport emissions in constructing the isopleths shown in Figures 8 and 9.

All Concentrations in $\mu g/m^3$, 1-Hour Average

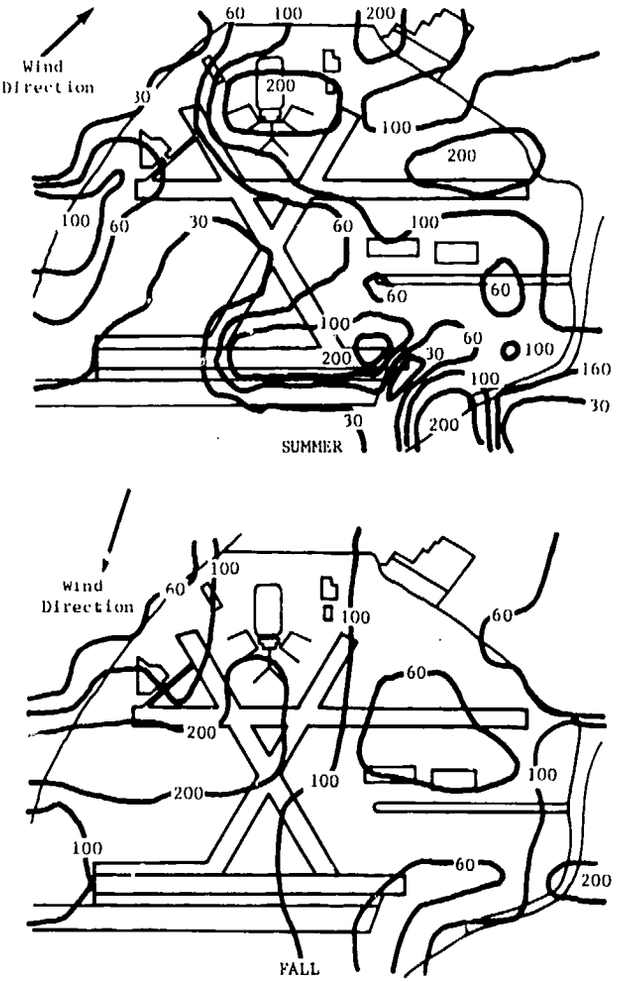


Fig. 8 - Predicted NO_x concentrations on airport property for normal conditions as taken from reference 5

However, an idea of the impact aircraft emissions may have on the predicted concentrations can be obtained from Table 2. The data on Table 2 shows the predicted NO_x concentrations at several of the receptor locations on the airport for the worst case situation. Also shown on Table 2 are corresponding NO_x concentrations which would occur if the NO_x emissions from aircraft were reduced by 45%. The 45% figure was derived by assuming that all aircraft operating at the airport met the current NO_x emission standard.

From Table 2 it can be seen that at the worst receptor on the airport (which is near the end of an active runway) a 45% reduction in aircraft emissions would reduce the NO_x concentrations by about 19%. At other locations on the airport property the 45% reduction in aircraft emissions has very little impact on predicted NO_x levels. Consequently, for the worst case situation examined, it appears that NO_x emissions from non-airport sources have a major impact on the predicted NO_x levels.

The effect of the aircraft emission standards

for the normal case can be seen by comparing Figure 10 with Figure 8. Through the comparison it can be seen that the standards tend to slightly reduce the

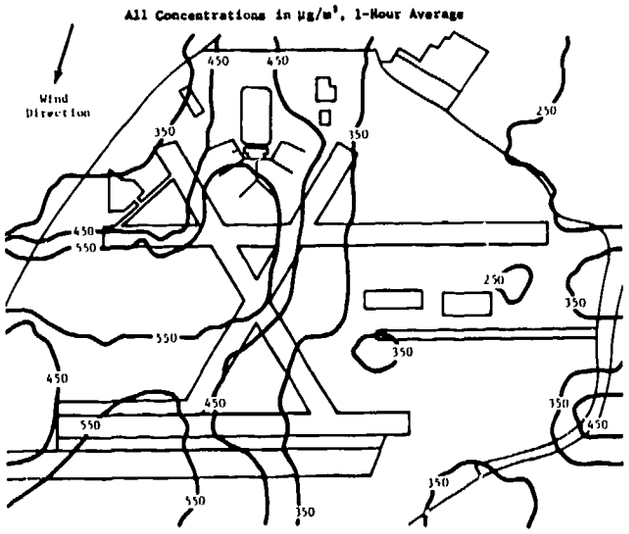


Fig. 9 - Predicted NO_x concentrations on airport property for worst case case situation as taken from reference 5

Table 2 - Impact on Maximum One-hour NO_x Concentrations ($\mu g/m^3$) at Worst Receptor Sites of a 45% Reduction in NO_x Emissions from Aircraft

Location	Worst Case Conditions: Baseline	45% Reduction in Aircraft Emissions	% Change
Parking Lot	489.7	489.7	-0-
Aircraft Ramp	578 8	565.6	-2.3
Delta Jet Base	296.2	295.7	-0.2
Eastern Hanger	352.0	351.5	-0.1
General Aviation Hangers	426.9	462.7	-0-
Cargo Area	371.0	371.0	-0-
Central Fire Station	330.8	321.8	-2.7
Worst Receptor	908.3	736.4	-18.9

size of the pockets of high NO_x concentrations. Also peak concentrations within these pockets are reduced, with the amount of the reduction strongly dependent upon location on the airport property.

Figure 11 provides an indication of the predicted impact the NO_x emissions from all airport sources (about 80% of which come from aircraft) would have on the air quality in areas around the airport. Note that for both the winter and summer cases there is a small pocket which extends off the airport property in which predicted one-hour NO_x levels could exceed 40 $\mu g/m^3$. Also it can be seen that the concentration of NO_x emissions from airport sources diminish very rapidly at only small distances away from the airport.

The total NO_x emissions from airport sources used in the Argonne analysis was approximately 2600

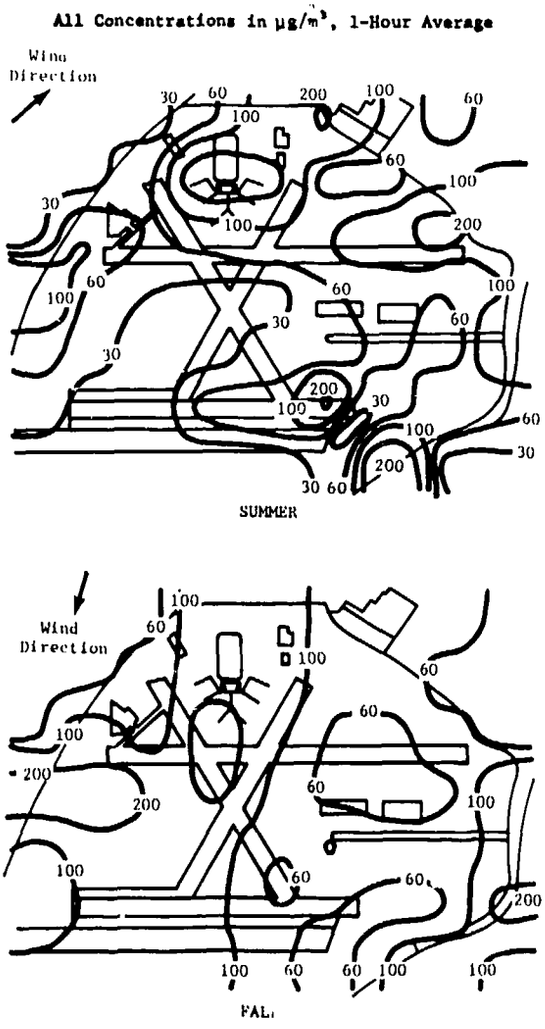


Fig. 10 - Predicted NO_x concentrations on airport surface as the result of a 45% reduction in emissions from aircraft (normal operating conditions)

tons/year (for normal case). This is about equivalent to a 100 megawatt power plant meeting the current New Source Performance Standard (NSPS). Figure 12 provides a comparison between the predicted maximum one-hour NO_x concentrations as a result of airport sources at locations from 2 to 14 kilometers downwind of the airport and at similar locations downwind of a 100 megawatt power plant. For this figure, it was assumed that the power plant met the current NSPS. From the figure, it can be seen that from 2 to 14 kilometers downwind, the NO_x concentrations from the power plant are projected to be over twice that caused by the airport sources. By comparison, a 100 megawatt power plant is considered to be a relatively small power plant.

The full application of proposed controls (9) is seen to have a calculable effect on airport emissions levels.

It should be pointed out that all the discussion for the Hartsfield Airport was based on the NO_x emission level for 1973. There has been some growth

All Concentrations in $\mu g/m^3$, 1-Hour Average

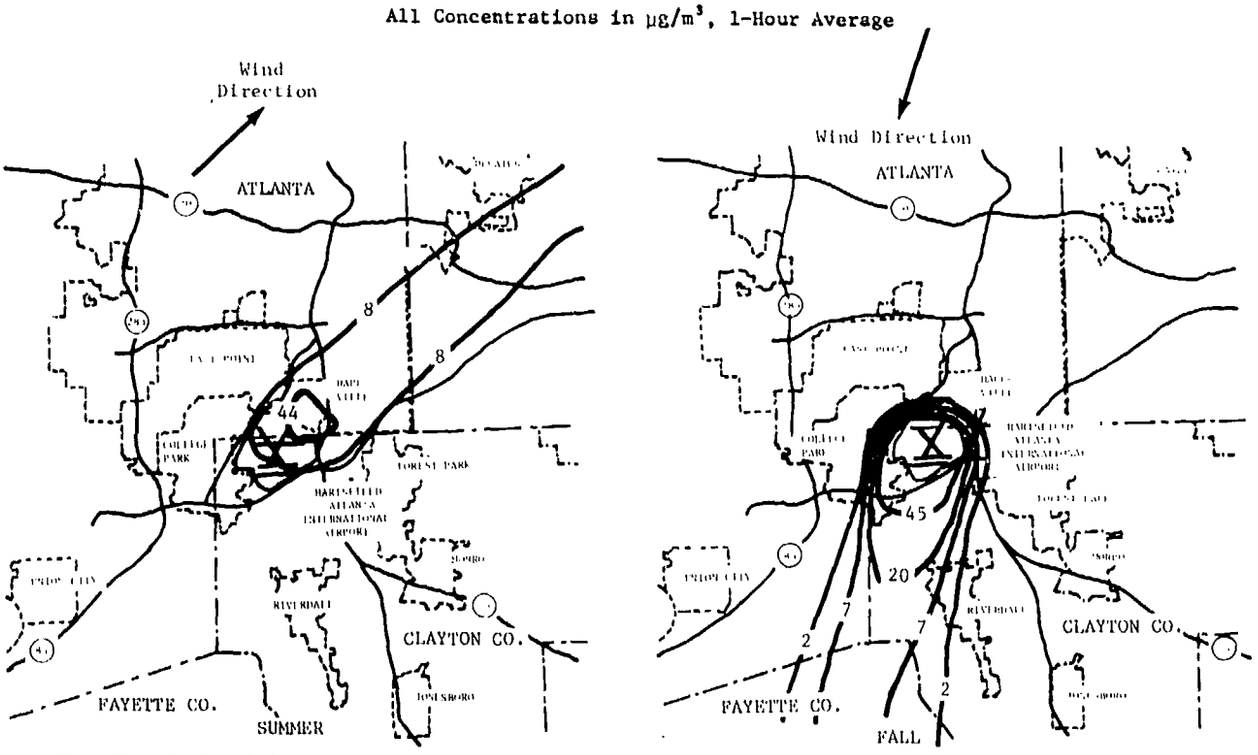


Fig. 11 - Regional Impact of NO_x emissions from airport sources alone under normal conditions

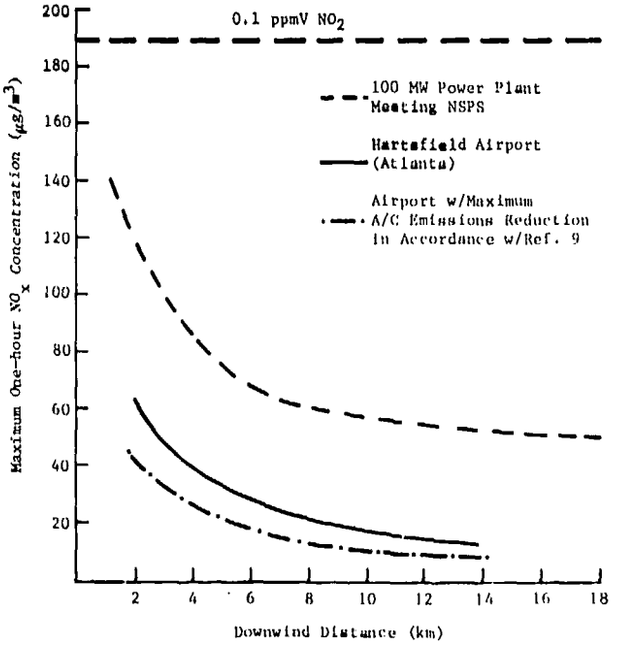


Fig. 12 - Comparison of maximum one-hour NO_x concentrations from airport sources downwind of Hartsfield International Airport with similar concentrations downwind of a 100 megawatt power plant

in NO_x emissions from aircraft since this time, both because of traffic increase and because of a trend toward higher NO_x emitting engines. However, it can be seen from Figure 12 that the NO_x from aircraft could be doubled and still not have any more impact on the area around the airport than a 100 megawatt power plant meeting the current NSPS. Also, it should be pointed out that the peak one-hour concentration for the power plant is 147 $\mu g/m^3$ whereas the peak concentration for the airport sources is 452 $\mu g/m^3$. The 452 $\mu g/m^3$ value varies on the airport property and is now shown on Figure 9.

RECENT MONITORING STUDIES AROUND MAJOR AIRPORTS

During the time period from May 16, 1976, to June 20, 1976, extensive air quality monitoring was performed in Mountain View, Georgia, which is a small community located just off the approach end of the main runway at Hartsfield International Airport, and directly beneath the flight path (airplanes overfly Mountain View at an altitude of 125 to 165 feet. Recorded hourly concentrations of NO_2 reached 220 $\mu g/m^3$ and during that month the average NO_2 was 80 $\mu g/m^3$. The results of this monitoring study are reported in (6).

The Mountain View monitoring study made no attempt to define the sources of the NO_2 and therefore is inconclusive regarding the impact aircraft emissions may have had on the recorded levels. However, the peak NO_2 levels recorded are just slightly above the lower limit of the WHO recommended NO_2 short-term standard. Also (6) concludes that it would appear from the data that there is little

chance that the annual NO_2 standard would be violated in the Mountain View area. It is, however, interesting to note that the modeling study previously discussed for Hartsfield Airport (5) indicates that airport sources contributed between 15 and 30% of the predicted annual average NO_x concentrations in the Mountain View area. This study also found that with a growth which would increase the NO_x emissions from airport sources by a factor of over 4, the annual average concentration of NO_x from airport sources in the Mountain View area would be about 60 to 70 $\mu g/m^3$.

Although unpublished as yet, the U.S. Air Force has recently completed an extensive monitoring study at Williams Air Force Base, Arizona. Williams is a busy Air Force Training Base. Preliminary analysis of this data had indicated that recorded hourly average levels of NO_2 are very low, approaching the detectable limit of the monitoring instrument. There are some indications that these recorded levels may have been affected by plume rise, however, as yet no final conclusions have been reached.

FUTURE GROWTH IN NO_x EMISSIONS FROM AIRCRAFT

There are strong indications that future aircraft engine designs will tend to produce large engines with increased NO_x emission levels as compared to present day engines. These large engines will tend to be used on aircraft with higher passenger capacity and thus on a per passenger basis, there will probably be a reduction in NO_x emission in the future. However, growth in the number of passengers is projected to result in an overall increase in NO_x emissions from aircraft in the future unless some form of control is implemented. This increase can range between 2 to 3 times current NO_x emission levels at the major airports (7). With this large increase in the projected levels of NO_x, aircraft emissions may have a much larger impact on NO_2 air quality, than at the present time.

SUMMARY

A number of studies have been conducted around major airports to assess the impact aircraft emissions may have on air quality in the vicinity of the airport. While over the last few years, there has been substantial improvement in capability to model airport emissions, as yet no definitive procedure has been developed for relating aircraft NO_x emissions to NO_2 air quality. Modeling studies, however, are consistent in indicating that very high levels of NO_x concentrations can be experienced at points on the airport property as a result of NO_x emissions from aircraft. However, most studies have indicated that the NO_x concentrations caused by aircraft emissions diminish very rapidly at small distances downwind of these pockets of high NO_x.

At least one study has indicated that high NO_x concentrations as a result of aircraft operations can extend beyond the airport property into neighboring business and residential areas at several of the largest airports. However, a reevaluation of this latter study has indicated that the NO_x emission from aircraft may have been overestimated, in some cases by a factor of over 2.

Examination of air quality monitoring data indicates that violations of the annual NO_2 standard can occur on the airport property. However, the available monitoring studies do not differentiate between the contribution of NO_2 caused by aircraft and those caused by other sources. Some of the modeling studies have indicated that nonairport sources contribute substantially to predicted NO_x concentrations on the airport property.

Because most of the NO_x emitted directly from aircraft exhaust is in the form of NO the impact of aircraft emissions on annual NO_2 air quality is believed to be considerably below that which would be predicted through modeling of ambient NO_x concentrations. This is because the conversion of NO to NO_2 requires some time to occur and generally is much slower at night than in the daytime and slower in winter months than in the summer months. Therefore, the use of NO_x concentrations to predict annual NO_2 levels probably overestimates the contribution by aircraft emissions to annual NO_2 levels on the airport property.

Under conditions where there is very rapid conversion of NO to NO_2, such as may be the case during a smoggy summer day, there are some indications that aircraft emissions may cause high hourly average concentrations of NO_2 to occur at localized spots on or very near to the airport property. If sufficient amounts of the NO is rapidly converted to NO_2, these concentrations may reach levels approaching the lower limit of recommended WHO short-term NO_2 standards. However, unless the current emission levels from aircraft are increased substantially, the available data suggest it is very unlikely that at the second busiest commercial airport in the country, violations of the recommended WHO standards would be caused by aircraft emissions alone.

By comparison, the NO_x emissions from aircraft at the second busiest commercial airport in the country are estimated to have less impact on NO_x concentrations downwind of the airport than would a 100 megawatt power plant located in the center of the airport and meeting the current NSPS for NO_x.

Aircraft emission controls appear to be effective in reducing NO_x concentrations at several "hot spots" on the airport property. However, at a distance of 2 kilometers downwind of the Hartsfield International Airport in Atlanta, aircraft emission standards have been projected to reduce maximum one-hour average NO_x concentrations by only 12 $\mu g/m^3$. This reduction becomes smaller at increasing distances from the airport property.

Because of the general trend to large engines which emit more NO_x, there are indications that growth in NO_x emissions from aircraft will be substantial in future years. In the absence of emission controls, such NO_x emissions could increase by a factor of 2 to 3 between now and the year 2000 at some of the major airports. This sharp increase can substantially increase the impact of aircraft emission on NO_2 air quality.

REFERENCES

1. U.S. Environmental Protection Agency, "An Air Pollution Impact Methodology for Airports - Phase I," APTD-1470, prepared by Argonne National Laboratory, January 1973.

2. U.S. Environmental Protection Agency,

"Aircraft Emissions: Impact on Air Quality and Feasibility of Control," Report to Congress, Undated.

3. U.S. Environmental Protection Agency, "Technical Report: Aircraft Emissions at Selected Airports 1972-1985," Draft Report prepared by Standards Development and Support Branch, Ann Arbor, Michigan.

4. Thayer, S. D., Pelton, D. J., Stadsklev, G. H., and Weaver, B. D., "Model Verification - Aircraft Emissions Impact on Air Quality," Geomet, Incorporated, EPA-650/4-74-049, May 1974.

5. Cicillo, R. R., Tschanz, J. F., and Camaioni, J. E., "An Evaluation of Strategies for Airport Air Pollution Control," Argonne National Laboratory, ANL/ES-45, March 1975.

6. Brown, K. W., Wiersma, G. B., and Hester, N. E., "Investigation of Soils and Vegetative Damage: Vicinity of Hartsfield, Atlanta's International Airport," U.S. Environmental Protection Agency, Monitoring and Support Laboratory, Las Vegas, Nevada.

7. "Major Issues to be Resolved Regarding the Aircraft Engine Emissions Standards," Draft report by U.S. Environmental Protection Agency, Office of Air and Waste Management, Washington, D.C., August 1977.

8. Federal Register, Vol. 43, pg. 12754, 1977.

9. U.S. Environmental Protection Agency, Notice of Proposed Rulemaking, Federal Register, March 24, 1978, pg. 12614.

DISCUSSION

ROTE: There is one point of confusion in your paper. In regard to the study that was done at Washington National, I believe you were referring to the study performed by Geomet, Incorporated, and my recollection of that study was they did not measure NO_2, but they measured NO_x.

They said they would report the data as NO_2. This is necessary whenever you do a measurement in parts per million and you wish to present the data in terms of micrograms per cubic meter--you must assign a specific molecular weight.

For example, if you measure hydrocarbons and you want to present your results in micrograms per cubic meter, you very frequently present them as though you were measuring methane.

In the case of the Geomet study, they measured NO_x and, for convenience, used the molecular weight of NO_2 in order to convert from parts per million to micrograms per cubic meter.

Unfortunately, that leads to confusion because people always see the results written as NO_2 and interpret the study as being an NO_2 measurement, but indeed it is an NO_x measurement.

As far as I know, there were no routine measurements made of NO. I raise this point for a good reason. There is a very important difference between doing measurements for the purpose of evaluating impacts and doing measurements for the purpose of validating a model.

At the time the study was performed, there was considerable discussion about what the objective of that study was.

EPA was primarily concerned with the problem of looking at impact. Geomet was very much concerned with the problem of model validation.

As a modeler, I would like to have seen measurements of NO-NO_2. EPA, for its own reasons, and I fully understand them, decided, no, NO_2 is the object for which the standard is written and, therefore, that is the object we should measure. But you can see the confusion, historically, that results from that kind of reasoning.

HUIE: In your figures, you seem to assume that the NO oxidation is solely due to the reaction with ozone. Was the possibility of oxidation of NO through hydrocarbon oxidation chains also considered or were these eliminated by modeling?

JORDAN: There may have been confusion there. In the modeling studies, no attempt at all was made to take into consideration the conversion of NO to NO_2.

Generally, what they said was it takes place anyhow within an hour or so, so the model itself does not take into consideration any of the mechanisms that would convert the NO to NO_2. My point was that you must not assume that because NO is there, it is going to become NO_2. It has to go through a conversion process. The process is most rapid when there is ozone present. Some of the other conversion processes do occur, but they are slower.

Unless there is something to prevent the dispersion, absolutely no wind, for instance, most of the NO would be greatly dispersed before the conversion is complete.

D. SMITH: I was wondering what progress has been made at EPA in defining the critical receptor concept in airports. In your Figure 9, you indicated if one set a new short-term standard, perhaps 500 micrograms per cubic meter, that that modeling exercise would indicate that somewhere on the airport property that level would be exceeded. But is that a critical receptor?

JORDAN: There is a major problem within the Agency, and that is trying to find out what is the ambient air and whom we are trying to protect. A massive study of these matters will be required. It will be some time before we can determine whether to set a standard based upon the possibility that someone might breathe too much NO at a particular spot on the airport property.

If there is a reasonable probability that the general public will be exposed to air pollutants in excess of what the medical people say is a health-related thing, then we would call that the ambient air.

As far as someone being exposed right out on the end of the runway, when typically nobody is out there, we would probably pass the problem on to OSHA.

AIR QUALITY IN THE VICINITY OF AIRPORTS

Charles M. Greenberg

THE BOEING COMMERCIAL AIRPLANE COMPANY

ABSTRACT

A carbon monoxide measurement program has been conducted at Seattle-Tacoma International Airport. This study was undertaken to investigate the basic tenet that airports contribute significantly to the degradation of air quality in and around the vicinity of airports. Initial measurements showed that levels of carbon monoxide on the airport grounds and in the surrounding environs were low when compared to the one-hour National Ambient Air Quality Standard. More recent measurements at other airports indicate similar results.

INTRODUCTION

Section 231 of the Clean Air Act, as amended by Public Law 91-604, directs the Administrator of the Environmental Protection Agency (EPA) to "establish standards applicable to emissions of any air pollutant from any class or classes of aircraft or aircraft engines which in his judgment cause or contribute to or are likely to cause or contribute to air pollution which endangers the public health or welfare."

Section 231 also directs the administrator to conduct a study of the extent to which aircraft emissions effect air quality throughout the United States and of the technological feasibility of controlling such emissions. A study was performed and a report entitled "Aircraft Emissions: Impact on Air Quality and Feasibility of Control" (Ref. 1) was later published by the EPA. The EPA concluded that aircraft emissions are significant contributors to the regional burden of pollution in comparison to other souces which will have to be controlled to meet National Ambient Air Quality Standards. The data base for the EPA was comprised of a number of documents including "Potential Impact of Aircraft Emissions Upon Air Quality" (Ref. 2), and "Jet Aircraft Emissions and Air Quality in the Vicinity of the Los Angeles International Airport (LAX)" (Ref. 3). In Reference 2 it is stated that aircraft emissions were found to be somewhat significant at receptors in "reasonable access" areas (defined as areas to which the general public has reasonable access for the averaging time specified in the air quality standard for the pollutant). The one-hour standard of 35 parts per million (ppm) for carbon monoxide was exceeded in "reasonable access" areas by as much as 38 ppm (aircraft contribution) at the study airports.

The Northern Research and Engineering Corporation (NREC) computer model (Ref. 2) was questioned with respect to accuracy and was further refined by GEOMET, Inc. (Ref. 3). A more recent report was prepared by Argonne National Laboratory (Ref. 4) which described the development of a computer model used to determine the impact of an existing or planned airport on the air quality in its vicinity. Part of the Argonne study was devoted to an air quality monitoring program, however, carbon monoxide was not included as one of the pollutants to be sampled.

The GEOMET and Argonne studies have more closely approximated the situation, but it is felt by The Boeing Company that CO monitoring at a number of airports is necessary to further define the picture. This is in agreement with the conclusions arrived at by Lorang (Ref. 5). It would give an enhanced data base for airport CO levels as well as provide information for future modelling efforts.

The Boeing Company set out to establish an air quality data base for Seattle-Tacoma International Airport (SEA) and Boeing Field International (BFI) to increase understanding of the effect that operating airports have on people at the airport and in neighboring residential areas. Questions to be determined include the following:

1. What levels of air quality exist on the airport grounds and do they exceed the allowable levels for protection of public health and welfare?
2. Do airports contribute to degradation of air quality in areas immediately surrounding airports?
3. How does the air quality at airports compare with air quality in residential, semi-industrial areas?

Sufficient manpower was not available for eight hours of continuous monitoring at numerous airport ground and periphery sites. However, by picking representative "hot spots" (areas that would be expected to have the highest levels of CO present), one can investigate the basic tenet that airports contribute significantly to the degradation of air quality in and around the vicinity of airports.

PROCEDURE

Between January 19, 1978 and June 21, 1978, air quality was monitored at two airports in the Puget Sound area of Washington State. The majority of data was collected at Seattle-Tacoma International Airport. Carbon monoxide and nitrogen dioxide readings were taken in various areas on the airport grounds. Carbon monoxide levels were also recorded in areas immediately adjacent to the airport in an effort to connect ambient CO levels near the airport with CO produced by processes taking place within the airport grounds.

The inital airport data were taken in a "roving" sense; follow and study any event or process which could lead to high localized levels of carbon monoxide or nitrogen dioxide in an effort to determine where the "hot spots" might be. Commercial aircraft emissions, service vehicle emissions and arterial traffic emissions were studied in an effort to determine what relative effect each had on the degradation of air quality. This report will discuss only CO test results as an analysis of NO_2 data has not yet been completed.

The roving tests consisted of several segments. Using an Energetics Science, Inc. Ecolyzer to analyze ambient levels of carbon monoxide, the area between Renton, Washington (Boeing Airplane Company facilities) and Seattle-Tacoma International Airport was traversed. (Renton is located eleven miles from Seattle on the southern end of Lake Washington and is included in the Seattle Metropolitan area.) This route includes one of the most heavily travelled roads in Renton followed by approximately four miles of freeway (I-405) whereupon one arrives at the airport. Measurements were taken on the return trip as well. Alternate routes were sometimes used in going to and coming from SEA-TAC Airport. Nineteen roving tests have been documented and the results from one test is shown in Figure 1 (Test 1).

Test 1 was run January 19, 1978 beginning at 9:20 a.m. The weather (as given by Air Traffic Information Service at Sea-Tac) was observed to be overcast with clouds at 5000 feet. Reports indicated a temperature and pressure of 51°F and 29.83 in Hg respectively. Winds were 5 Knots at 360°. This translates to a Pasquill-Turner D stability class situation.

Renton automobile traffic levels averaged 14 to 16 parts per million CO with peaks of 90 ppm and 40 ppm during heavy stop and go traffic. Freeway levels were stable at around 8 ppm CO.

Airport background carbon monoxide levels were observed to be approximately 4 parts per million. A peak of 30 ppm was observed while fifty feet directly behind a Boeing 727, returning to background levels within one minute. Passing a DC-10 with its auxilliary power units running gave a CO level of 10 ppm.

All nineteen tests of this nature were taken to give a better feel for average ambient levels of CO, to determine where high levels would occur, and to specify what would be a good sample time to achieve a representative sample.

Based on results of the roving tests, "hot spots" (defined earlier) were selected which would be most likely to exceed National Ambient Air Quality Standards (NAAQS). Ten positions on the airport grounds were picked (some as potential violators - some as reference points - see Figure 2). Also selected for study were nine areas located near the airport grounds (see Figure 2).

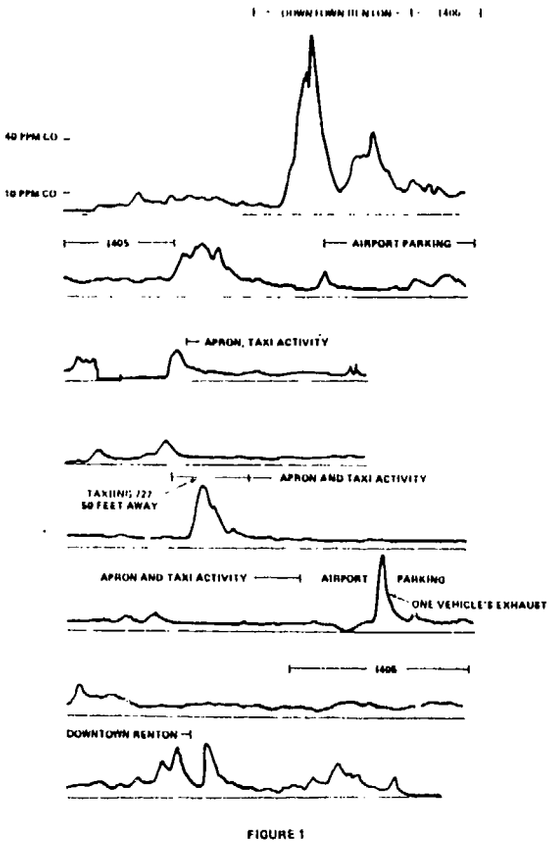


Fig. 1 - Roving test 1, carbon monoxide levels

The ten airport hot spots selected were (also see Figure 2):

1. East side of terminal
2. West side of terminal
3. North end of field - north holding ramp
4. North end of field - west perimeter road
5. Middle of east taxiway
6. East of north satellite
7. Northwest side of terminal
8. South end of field
9. Southwest corner of field
10. South end of east taxiway
(for more detail see Appendix I.)

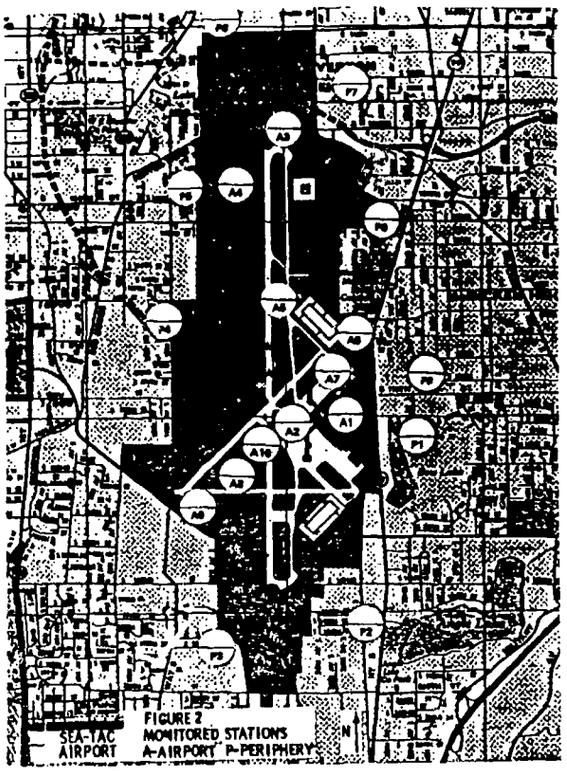


Fig. 2 - Location of airport and periphery monitor stations at SEA-TAC Airport

There were two observers, each with portable equipment for measuring carbon monoxide levels. One observer recorded measurements at each of the ten airport stations while the second performed similar measurements at the nine periphery locations. An Interscan model 1415 CO/NO_2 analyzer was used for airport grounds measurements (with both CO and NO_2 being measured.) The Energetics Science Ecolyzer (CO Analyzer) was used for the periphery measurements. Each observer sampled air quality for 12 minutes at a station, then moved on so as to sample his nine (or ten) stations within 2 to 3 hours.

The daily airplane departure data for Seattle-Tacoma International Airport shows that while the number of departures taking place is a strong function of the hour of day (see Figure 3), the variability is small from day to day. We may presume then that our data base is a function of the time of day we obtained the data (along with meteorological influence) and not the day of week. Hourly data for the number of departures and arrivals taking place is shown in Table I. These data show that a maximum airplane departure rate occurs between 6:00 and 9:00 a.m. An extended peak occurs between 10:00 a.m. and 1:00 p.m. with aircraft arrivals and departures contributing an equal amount. Further, there is a peak due to arrivals between 4:00 and 5:00 p.m.

Weather observations were obtained from the Air Traffic Information Service on days and hours that tests were run and are shown in Figure 4.

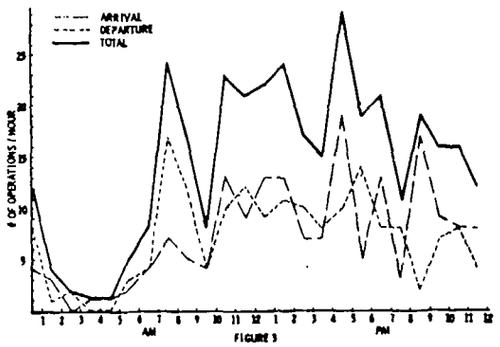


Fig. 3 - Number of aircraft arrival and departure operations per hour plotted against time of day at SEA-TAC Airport

Table 1 - Aircraft Arrivals and Departures Averaged According to Time

TIME	DEPARTURES	ARRIVALS	TOTAL
12-1 a.m.	8	4	12
1-2	1	3	4
2-3	2		2
3-4		1	1
4-5		1	1
5-6	3	2	5
6-7	4	4	8
7-8	17	7	24
8-9	12	5	17
9-10	4	4	8
10-11	10	13	23
11-12	12	9	21
12-1 p.m.	9	13	22
1-2	11	13	24
2-3	10	7	17
3-4	8	7	15
4-5	10	19	29
5-6	14	5	19
6-7	8	13	21
7-8	8	3	11
8-9	2	17	19
9-10	7	9	16
10-11	8	8	16
11-12	4	8	12

WEATHER CONDITIONS

	PDT	CLOUD COVER	TEMP	WIND
6-29	11:51	1/10 500 Cumulus Fractus 4/10 1000 Strato cumulus 1/10 2000 Strato Cumulus	62	220° @ 7 Kts
6-30	10:51	6/10 Cumulus 1600 2/10 Cumulus 7000	66	210° @ 8 Kts
7-6	11:50	8/10 Scattered 1000	67	320° @ 8 Kts
7-7	9:51	300 ft Fog Overcast	59	250° @ 5 Kts
7-10	2:45	6/10 Cumulus 2000 3/10 Strato-Culumus 4000	63	220° @ 12 Kts
7-12	11:00	0/10 CuFra 1000	67	20° @ 9 Kts
7-13	11:00	1/10 CS 25,000	72	310° @ 5 Kts
7-14	1:00	8/10 AC 15,000	73	290° @ 7 Kts
7-17	2:00	7/10 SC 2500 3/10 SC 3500	65	280° @ 6 Kts
7-18	3:00	7/10 C 1100	69	320° @ 7 Kts
7-19	12:00	3/10 Scatt 7000	74	10° @ 8 Kts
7-20	10:00	0/10 Cumulus 5000 0/10 CI 25,000	83	320° @ 15 Kts
7-21	7:00		65	CALM
7-24	3:00	0/10 SC 2000	70	260° @ 10 Kts
7-25	3:00	3/10 CI 30,000	86	290° @ 6 Kts
7-26	12:00	6/10 CB 4500 4/10 AC 9000	68	270° @ 7 Kts
7-27	11:00	10/10 SC 3000	65	280° @ 8 Kts
7-28	10:00	2/10 SC 1700 3/10 SC 4000 0/10 C 27,000	66	30° @ 7 Kts
8-1	11:00	10/10 Stratus 500	56	230° @ 6 Kts
8-2	11:00	10/10 Fog	58	260° @ 6 Kts
8-2	5:00		74	310° @ 5 Kts
8-3	3:00		81	300° @ 10 Kts
8-4	12:00	Scatt 2000 Scatt 13,000	70	310° @ 7 Kts
8-7	8:00	Clear	66	20° @ 8 Kts

FIGURE 4

Fig. 4 - Weather observations during test runs at SEA-TAC Airport

RESULTS

Between July 7, 1978 and August 6, 1978 twenty tests were run for the three most common atmospheric stabilities (B,C,D). It is expected that this sampling program will be of one year in duration so as to give better confidence levels and to encompass any and all seasonal trends which might occur.

Table 2 shows the 12-minute averaged periphery carbon monoxide levels at each station on each day of sampling. Table 3 shows the airport results in a corresponding manner.

In order for a day's data set to be labelled as a test run it had to fulfill two prerequisites: (1) both data samplers had to be taking samples within roughly the same time frame (early morning, late morning, early afternoon, etc.) (2) the test would be void if the weather changed significantly during the test run.

Data was rounded to the next higher whole number to reflect instrument error, zero offset and linearity problems.

In looking at periphery data (Table 2), one should note that in only one case does the carbon monoxide level exceed four parts per million for a 12-minute sample. Observing the continuous output to be fairly constant in addition to spot checks which were frequently performed, it is likely that these values are representative of the hour during which they were taken. With the one-hour violation for carbon monoxide set at 35 parts per million it becomes apparent that nowhere on the periphery are people subjected to levels of carbon monoxide which would constitute a one-hour violation.

An attempt was made to correlate atmospheric stability with ambient levels of carbon monoxide. No strong correlation was found. Tables 2 and 3 show the average CO level as a function of station.

Table 2 - Results from Periphery Stations in Parts per Million

DATE:	STATIONS: 1	2	3	4	5	6	7	8	9	Test #
7/7	2	1	2	2	1	2	2	2	1	1
7/12	1	1	1	1	1	1	1	1	1	2
7/13	2	1	-	1	1	1	1	2	2	3
7/14	3	2	2	2	4	2	2	3	3	4
7/18	1	1	1	1	2	1	1	1	1	5
7/19	1	2	1	1	1	1	1	1	1	6
7/20	1	1	1	1	1	35	55	1	1	7
7/21	7	4	2	4	4	4	4	1	4	8
7/24	2	1	1	1	2	1	1	1	1	9
7/25	1	1	1	2	2	1	2	1	1	10
7/27	2	1	1	1	1	1	1	1	2	11
7/28	2	2	2	2	2	2	2	2	2	12
8/2	2	2	2	2	2	2	2	2	2	13
8/3	2	2	1	1	1	1	1	2	2	14
8/7	2	2	1	1	1	1	1	2	2	15
8/4	2	2	2	2	2	2	2	2	2	16
8/9	1	1	1	1	1	1	1	2	2	17
8/9	2	1	1	1	1	1	1	1	1	18
8/10	2	2	1	2	1	1	2	2	3	19
8/16	1	1	1	1	1	1	1	1	1	20

Table 3 - Results from Airport Stations in Parts per Million

DATE:	STATIONS: 1	2	3	4	5	6	7	8	9	10	TEST #
7-7	0	0	0	0	1	0	0	0	0	0	1
7-12	0	0	0	0	0	0	0	0	0	0	2
7-13	0	0	0	0	0	0	0	0	0		3
7-14	12	0	0	0	0	0	0	0	0		4
7-18	0	0	0	0	0	0	0	0	0	0	5
7-19	0	0	0	0	0	0	0	0	0	0	6
7-20	0	0	0	0	0	0	0	0	0	0	7
7-21	0	0	0	0	0	0	0	0	0		8
7-24	0	0	0	0	0	0	0	0	0	0	9
7-25	0	0	0	0	0	0	0	0	0	0	10
7-27	0	0	0	0	0	0	0	0	0	0	11
7-28	0	0	0	0	0	0	0	0	0	0	12
8-2	0	0	0	0	0	0	0	0	0	0	13
8-3	0	0	0	0	0	0	0	0	0	0	14
8-7	0	0	0	0	0	0	0	0	0	0	15
8-4	0	0	0	0	0	0	0	0	0	0	16
8-9	0	0	0	0	0	0	0	0	0	0	17
8-9	0	0	0	0	0	0	0	0	0	0	18
8-10	0	0	0	0	0	0	0	0	0	0	19
8-16	0	0	0	0	0	0	0	0	0	0	20

At most of the periphery stations the levels were two parts per million or less.

On the one day where the winds were found to be less than three knots, the CO values were seen to be significantly higher at most stations (see Figure 5).

In another case when the wind was from the west (typical) the CO levels directly east of the airport grounds did not reflect any increase from that observed directly west of the airport (see Figure 6). Station 3 (north end of runway) showed lower levels than studies at other airports had indicated.

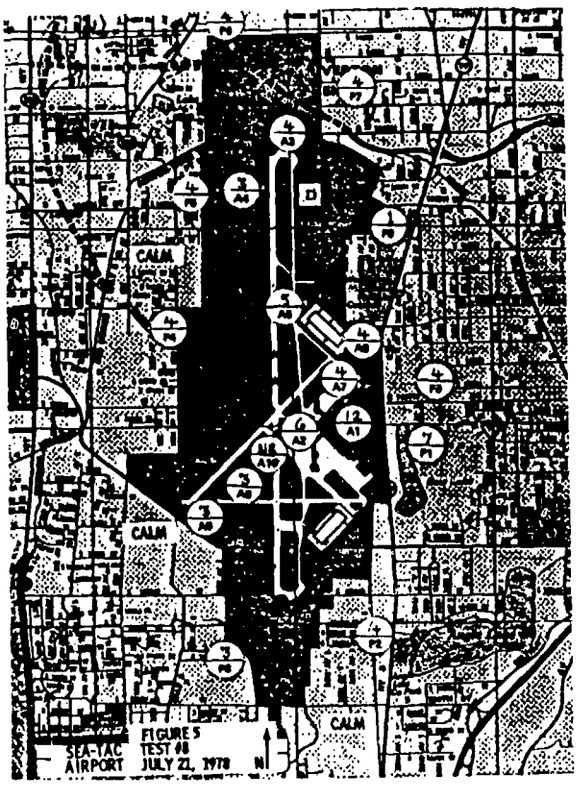


Fig. 5 - CO concentrations for test 8 - July 21, 1978 at SEA-TAC Airport

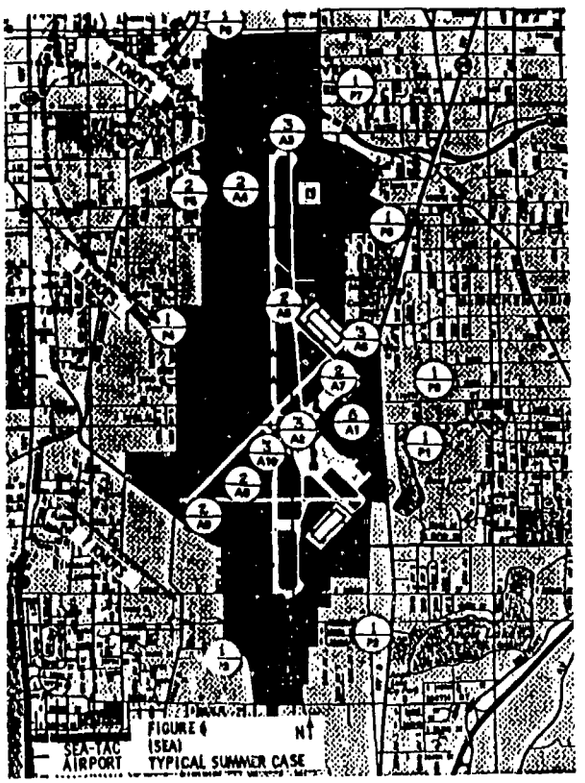


Fig. 6 - CO Concentrations for typical summer case at SEA-TAC Airport

CONCLUSIONS

There were no one-hour CO violations found either on the airport grounds or in neighboring areas for the course of this study. The highest levels were found at Ground Transportation Loading/Unloading Areas.

It was found that the airport had very little effect if any in areas immediately adjacent to the airport. Also, air traffic activity was not reflected in airport or periphery CO levels.

ACKNOWLEDGEMENTS

The author wishes to gratefully acknowledge the assistance provided by officials at Seattle-Tacoma International and Boeing Field International Airports.

I also wish to express my appreciation for help given by officials at Los Angeles in allowing me to acquire data for use in the presentation of this paper.

Appendix 1 - Station Description - Sea-Tac CO-NO_2

Monitoring Network

No. 1 The lower of the two vehicle terminal access drives has less air movement due to the greater depth of the building canyon and the overhead pedestrian crossings.

No. 2 The bus stop is a 8xl2x7 foot plywood shelter which does not cause any large scale change of air motions in the area. Instruments are placed on the low wall just behind the shelter and about 6 feet north. There are numerous vehicles within 50 feet, passing by, or stopping briefly.

No. 3 Two stations at the north end of the field define the zero and moderate levels of aircraft-caused pollution. No. 3 is on the leeward side of the usual takeoff point and yields some small increases in CO and NO_2 levels with each passing airplane, which are 150-200 feet away.

No. 4 Across from No. 3, this station has not sampled any aircraft exhaust because there are few, if any, takeoffs on 16R. In addition, it is about 500 feet from the centerline of 16R (34L). Low pollutant levels were due to lack of aircraft contribution and minimal auto traffic in the residential area to the west.

No. 5 The taxiway near station No. 5 usually has the highest number of aircraft movements of any point on the airport. Every airplane taking off to the south must taxi by and most of the landings on 16L turn off on the adjacent broad ramp connecting 16L and the taxiway. Automobile traffic is about 100 feet away and moderate to heavy, serving the air freight complex. Exposure is good all year around.

No. 6 East of the north satellite and overlooking North Entry Drive, this point is open to any westerly flow carrying exhaust from United, Alaska, Braniff, Hughes and some Continental aircraft.

No. 7 There are more aircraft movements here than at station No. 6, with less chance for air movement.

No. 8 The south end of the airport has little contamination because of the low percentage of easterly components of the wind.

No. 9 Due west of No. 8 about 1500 feet, this station is close to some commuting traffic.

No. 10 As one of the busiest spots on the airport, it also is nearest the transient aircraft parking area.

REFERENCES

1. Aircraft Emission: Impact on Air Quality and Feasibility of Control, EPA, 1972.

2. The Potential Impact of Aircraft Emissions Upon Air Quality, Northern Research and Engineering Corporation, Report No. 1167-1, Contract No. EPA-68-02-0085, December 29, 1971.

3. Model Verification - Aircraft Emission Impact on Air Quality, GEOMET Incorporated, September 1974.

4. Airport Vicinity Air Pollution Study, Argonne National Laboratory, Contract No. DOT FA1WAI-223.

5. Review of Past Studies Addressing the Potential Impact of CO, HC, and NOx Emissions from Commercial Aircraft on Air Quality, March 1978, AC 78-03.

DISCUSSION

GORDON: Have you made, or do you intend to make, any statistical correlations--at SEATAC primarily--between aircraft operation activity and measured CO level, and do you intend to try to separate the contributions from aircraft versus ground vehicular sources?

GREENBERG: Not rigorously, no. We picked certain stations because they would be more highly influenced by certain aspects of the operations taking place around the airport. At certain of our airport stations, for instance, the airplanes would be queuing, ready to take off, etc. We picked one station at SEATAC that was highly influenced by both service vehicle activity and airplane activity and the various satellites.

We don't plan to do anything rigorously to say what percent was contributed by what mode, although we can get a good idea as to what the influences were in the varying areas.

The instrumentation we used was an Ecolyzer and an Interscan. They give relatively inexact answers.

TESCHE: You indicated that there were significantly higher levels near the Worldway area. Could you comment on what that magnitude might be.

GREENBERG: Yes. As a matter of fact, I can show a foil. We were limited in our time for taking samples because LAX was so busy.

You see significantly higher values in passenger loading and unloading areas from the ground transportation. Of course, in SEATAC you are located in sort of a canyon. You have to conclude it is all automotive traffic at SEATAC.

This is LAX data. These are only five-minute samples, but they do give an indication that there are somewhat higher values.

JORDAN: The last conclusion was that there was a correlation between the CO measured and the aircraft activity.

I think Howard Segal is going to present some measurements he and I made at Lakeland. We found this correlation, too, near the end of the runway where the aircraft are queuing up.

There is a correlation between the CO amount and the aircraft activity. It isn't necessarily a bad problem. The levels we reported were low and we did see this correlation.

I also wanted to point out that we (FAA and EPA) are setting up an extensive monitoring study again at Washington National, just to observe what we were talking about here, for the taxiing and queuing modes. These cause the biggest CO problem.

GREENBERG: I might add one interesting point. We saw a lot of significant contribution from service vehicle activity. At LAX it is very, very convenient.

You can get right out there with the queue on the northern runways, and I observed during high activity times. I was no more than 200 feet away at a point labeled "P" on the periphery. We had another observer closer to the aircraft activity. We didn't see any increases on the average at that station where we had expected them.

We didn't see anything due to queuing aircraft. We could get very close and make good judgments as to what was causing the problem because we had a fairly good west wind.

AIRPORT SOURCES AND EMISSIONS DATA BASE

Chairman: H. A. Panofsky

Penn State University

AIRCRAFT TURBINE ENGINE PARTICULATE EMISSION CHARACTERIZATION

John D. Stockham, Erdmann H. Luebcke
IIT Research Institute
Chicago, Illinois, U.S.A.

and

Larry Taubenkibel
DOT - Federal Aviation Administration
Washington, D.C., U.S.A.

ABSTRACT

A particulate matter sampler is described along with operational experience and the data obtained using the sampler on the JT8D and JT9D aircraft turbine engines. The sampler acquires a sample of the exhaust particles emitted during the ground operation of the engine and permits the characterization of the mass concentration, elemental composition, particle size distribution, and particle morphology. Mass concentration is obtained gravimetrically. Elemental composition is obtained by energy dispersive X-ray and particle size and shape by electron microscopy and image analysis. Particle size data is also obtained with the Electrical Aerosol Analyzer.

The sample is extracted from the exit plane of the engine. The sampling probe geometry corresponds to the FAA's recommended methodology for gaseous emission sampling. The extracted sample is conditioned through dilution to minimize local condensation, particle deposition, and sample bias before collection on substrates suitable for analysis.

THE PHYSICAL AND CHEMICAL CHARACTERIZATION of particles emitted by aircraft turbine engines has not received comprehensive investigation. Therefore, a sampling system was designed and constructed to collect particles from aircraft turbine engines (1, 2).* The sampler is specifically designed to collect representative samples of particulate matter from the exhaust at the exit plane of low bypass ratio, mixed flow, and high bypass ratio aircraft turbofan engines operating in an engine test cell. These engine types are represented in the current commercial fleet by the JT3D, JT8D, and JT9D series of engines. The sampler uses a mixing type sampling rake, a specialized aerosol transport and conditioning system, and sample collection near the engine to minimize particle deposition, re-entrainment, and agglomeration during transport. A feature of the sampler is the bifurcation of the extracted exhaust sample - a large portion for bulk analysis and a smaller portion for detailed particle characterization.

SAMPLER DESCRIPTION

A flow diagram of the sampler is shown in Figure 1. A "diamond" shaped sampling rake mounts directly behind the engine exhaust plane. An extraction nozzle is located at the midpoint of each leg of the diamond. The four nozzles are evenly spaced on an arc whose radius is 62% of the engine's exit plane radius. The leading edge of the nozzle extends about ten diameters upstream of the support structure. The nozzle diameters are 0.170 ± 0.008 cm. The geometry of the rake corresponds to that recommended by the Federal Aviation Administration (FAA) for gaseous emission sampling and has been shown to give comparable results to a 24 sampling nozzle rake system (3). The four sampling nozzles are manifolded to provide a composite sample. The manifold is connected to the primary diluter via a flexible coupling that accommodates movement of the engine during testing.

The function of the primary diluter is to condition the extracted particulate matter sample. The sample is cooled without passing through a dew point and diluted to reduce particle agglomeration effects. The unique design of the diluter reduces wall losses and aids in the preservation of particle mass and particle size distribution (4, 5). The diluter consists of a porous tube housed within a larger tube. Clean, dry, metered, compressed air is delivered to the annular space at four locations and flows through the porous inner tube providing a clean boundary layer that reduces particle deposition and subsequently mixes with the sample to provide dilution and temperature control.

After conditioning, the sample is bifurcated. The majority of the sample is transported to the mass sampling turret where the particulate matter is removed by filtration onto tared Gelman, type AE, glass fiber filters, 142 mm in diameter. A smaller portion of the sample is adjusted in concentration by a secondary diluter similar in design to the primary diluter and transported either to the Electrical Aerosol Analyzer (EAA) for real-time particle size distribution measurement or for collection onto membrane filters and electron microscope grids for subsequent analysis of particle size, shape, and elemental composition. The membrane filters used are 0.03 μm pore size Nuclepore filters, 47 mm diameter.

With the exception of the EAA, the sampler is designed for operation in close proximity to an operating turbine engine. All functions of the sampler, therefore, are remotely controlled from a centralized control panel that can be located up to 25 feet from the filtration units in a safe location such as the test cell control room. The EAA con-

*Numbers in parentheses designate References at end of paper.

tinuously malfunctioned in the test cell environment despite efforts to provide a suitable sound protection enclosure. As a result, the EAA is operated in the test cell control room.

Flow control valves for the sampler are located downstream of the particle collection sites to eliminate particle deposition in the valve assembly. This requirement imposed operational constraints in the system -- each sample has to be acquired sequentially and flow switching procedures must be carefully performed to prevent rupture of the filters. Also, because the extracted sample flow from the engine is not measured directly, the primary diluter flow and the total sample flow have to be accurately determined. The dilution flow rates are measured by precision drilled orifices; total flow is measured with a hot-wire anemometer. The uncertainty in total flow measurement is ±0.09 std. m^3/hr. while the dilution flow is repeatable to approximately ±0.1 std. m^3/hr. The maximum error in the extracted sample flow measurement occurs at idle power and is on the order of 10%.

The turret assemblies for sample collection provide positions for six filters. Samples, thus, can be acquired at five engine power settings -- idle, approach, cruise, climb-out, and take-off -- before the engine needs to be shut down and the filters recovered. The sixth turret position is a dummy used during start-up, shut-down, and while power settings are being changed and engine operation stabilized.

The sampler is designed for isokinetic sampling of the exhaust from the JT8D and JT9D engines at power settings from idle through cruise. At climb-out and take-off power, sonic conditions are approached at the engine's exit plane and sampling at this rate would cause severe flow complications resulting in modification of the extracted exhaust particles. The flow through the extraction nozzles was, therefore, limited to a local Mach number of 0.8. Extracted sample flow ranged from 0.9 std. m^3/hr. to 4.8 std. m^3/hr. for engine power settings from idle to take-off (6).

TEST SITE AND DATA ANALYSIS PROCEDURES

The particulate matter sampler was operated at United Airlines' San Francisco, Ca., Maintenance Facility on JT8D and JT9D aircraft turbine engines. Figure 2 shows the sampler set-up in a JT9D test cell. Due to United's fleet needs, sampling time was at a premium and several different engines were used during the test series. The engines tested are given in Tables 1 and 2 along with data on the mass emission rate and the particle size distribution of the exhaust particles as determined by electron microscopy and image analysis. In addition, particle size distribution measurements were made with the EAA and particle shape was determined by image analysis. Two fuels were used during the test series, pearl kerosene (PK), a high hydrogen, low aromatic content fuel, and JET A, a standard commercial aircraft turbine engine fuel with a lower hydrogen and higher aromatic content. The use of two fuels permits the determination of the effect of fuel composition on emissions. A single batch of PK fuel was purchased and stored at United's facility. Its composition, therefore, was constant throughout the tests and repeatability measurements were possible. JET A fuel composition varied during the tests. All fuels were sampled and analyzed; significant data is given in Table 3.

Mass emission rates were determined by differential gravimetric analysis. A Gelman, type AE, glass fiber filter was used to collect the particulate matter for mass determination. The filters were weighed on an analytical balance before and after sample collection and corrected for shifts in weight due to hygroscopic effects with control filters.

Particle size data was obtained by two methods. One method used, the Electrical Aerosol Analyzer (EAA), provided a real-time measure of the particle size distribution. The EAA used was Model 3030, Thermo-Systems, Inc., St. Paul, Mn. The instrument was operated in accordance with the operating and service manual provided with the instrument.

The second procedure used for particle size analysis was electron microscopy and image analysis. The samples, collected on Nuclepore membrane filters or carbon coated electron microscope grids attached to the membrane filter, were used in the analysis. The electron microscope used was the JEOL-100C analytical scanning/transmission microscope equipped with an energy dispersive X-ray system for elemental analysis. After applying a thin film of gold to the filter surface with a Hummer II plasma specimen coater, the samples were observed and photographed in the scanning microscope at several magnifications ranging from 10,000 to 100,000X. A magnification of 30,000X was found to be optimal for particle size and shape analysis. Particle size and shape analysis were performed by interrogating the electronphotomicrographs with an Imanco Quantimet 720 Image Analyzer. Particle size was computed from the area measurement of each particle. The particle size reported, thus, represents the diameter of a circle of area equal to that of the particle.

Particle shape was determined using the image analyzer and interrogating the particles for their area and perimeter. A two-dimensional shape factor was then calculated from the ratio A/P^2. This ratio was plotted as a function of the equivalent area particle diameter.

Elemental composition of the particles was determined while the particles were under observation in the electron microscope. A Kevex energy dispersive X-ray spectrometer coupled with the Tracor/Northern 880 X-ray analysis system was used.

RESULTS AND DISCUSSION

MASS EMISSIONS -- Mass emission data are reported in Tables 1 and 2 and plotted for the JT8D engine as a function of primary air flow in Figure 3. The data show an increasing emission rate with power. The emission rate ranged from 0.15 kg/hr. at idle to a range of 0.25 to 4.62 kg/hr. at climb-out and 0.76 to 1.79 kg/hr. at take-off. Data for the JT9D engine show a similar trend and the same order of magnitude. However, primary air flows for the JT9D engine are significantly greater. Primary air flows as a function of engine power is given in Table 4. With the restricted sampling time available, 12-30 minutes depending on the operating mode,

Table 1 -- Summary of Turbine Engine Sampling Data - JT8D

Sample Date	Engine Type	Engine Number	Fuel	Operating Mode	Primary Air (kg/sec)	Particle Emission (kg/hr)	Particle Size Distribution[1]	
							$(d_g, \mu m)^2$	$(\sigma g)^3$
1/10/78	JT8D-7	654957	JET A	Idle	16	0.15	0.052	1.7
				Approach	33	1.00	0.086	1.7
				Cruise	50	1.78	0.081	1.7
				Climb-out	61	2.97	0.096	1.6
				Take-off	68	0.95	0.099	1.7
4/24/78	JT8D-15	648796	JET A	Idle	17	--	0.042	1.7
				Approach	33	0.30	0.067	1.8
				Cruise	50	1.03	0.092	1.8
				Climb-out	62	4.62	0.088	1.9
				Take-off	69	--	0.097	2.0
4/25/78	JT8D-7	648735	JET A	Idle	17	--	0.043	1.6
				Approach	33	0.34	0.054	2.1
				Cruise	49	0.25	0.069	2.0
				Climb-out	61	0.25	0.049	2.3
				Take-off	68	0.76	0.060	2.2
6/20/78	JT8D-15	696572	JET A	Idle	17	--	0.042	1.7
				Approach	33	0.24	0.066	1.7
				Cruise	50	1.12	0.071	1.9
				Climb-out	62	0.74	0.079	1.6
				Take-off	69	1.38	0.080	1.6
4/24/78	JT8D-15	648796	PK	Idle	17	--	0.032	1.7
				Approach	33	0.08	0.043	1.8
				Cruise	50	0.24	0.079	1.9
				Climb-out	62	1.27	0.075	1.8
				Take-off	69	1.79	0.077	1.9

[1]Obtained by electron microscopy and image analysis
[2]Geometric mean particle diameter
[3]Geometric standard deviation

Table 2 -- Summary of Turbine Engine Sampling Data - JT9D-3A

Sample Date	Engine Number	Fuel	Operating Mode	Primary Air (kg/sec)	Particle Emission (kg/hr)	Particle Size Distribution[1]	
						$(d_g, \mu m)^2$	$(\sigma_g)^3$
1/9/78	662734	JET A	Climb-out	99	--	0.084	1.6
			Take-off	111	--	0.117	1.6
4/21/78	663031	JET A	Approach	62	0.60	0.054	1.8
			Take-off	111	2.87	0.077	1.8
6/21/78	663082	JET A	Idle	30	--	0.041	1.5
			Approach	62	--	0.047	1.7
			Cruise	82	0.32	---	-
			Climb-out	99	--	0.040	1.8
6/22/78	662794	JET A	Cruise	82	--	0.041	1.7
			Climb-out	99	0.22	0.045	1.6
4/21/78	663031	PK	Approach	62	1.33	0.054	1.6
			Take-off	111	--	0.050	1.9

[1]Obtained by electron microscopy and image analysis
[2]Geometric mean particle diameter
[3]Geometric standard deviation

and the low emission rates for the JT8D and JT9D engines, the gain in filter weights were only a few milligrams. Additional testing with longer sampling times are needed for a more accurate determination of mass emission rates. Earlier data (2) collected from a TF-30 engine suggest the sampler can reproduce mass concentration data within ±2% at the cruise power setting for this engine. Effects of engine and fuel variability are discernible, however. The JT8D-7 engine, 648735, gave lower emission rates than the other engines and the JT8D-15 engine tested with both JET A and PK fuel gave a lower emission rate with the PK fuel.

PARTICLE SIZE DATA -- Particle size data obtained by electron microscopy and image analysis are reported in Tables 1 and 2 and summarized in Tables 5 and 6. For the JT8D engines, operating on JET A fuel, the average geometric mean particle size, $\bar{d}g$, increased with engine power. At idle, $\bar{d}g$ was 0.045 μm, at approach $\bar{d}g$ was 0.068 μm, at cruise and climb-out $\bar{d}g$ was 0.078 μm, and at take-off $\bar{d}g$ was 0.084 μm. Particle size is influenced by fuel type; PK fuel gave smaller particle sizes. This is consistent with the lower mass emission rate found for the engine when operated on PK fuel. Also consistent is the performance of JT8D engine 648735. This engine, which produced the lowest emission rates, also produced the smallest particle sizes. The geometric standard deviations for the particle size distributions ranged from 1.6 to 2.3. Engine 648735 gave the widest distribution of particle sizes. The JT9D engines gave similar trends to the JT8D engines, but indications are that the particles are smaller.

Particle size distribution data were also obtained with the EAA. Typical data for the JT8D and JT9D engines are plotted in Figures 4 and 5. These data support the results obtained by the electron microscope and image analysis measurements. Higher power settings produce a greater concentration of particles in all sizes ranges above about 0.02μm. Below 0.02μm, data is conflicting but the performance of the EAA is known to be erratic in this range (7). Particle concentration for the JT8D engine is about one order of magnitude greater than for the JT9D engine. The influence of fuel composition on particle size is illustrated in Figures 6 and 7 for the JT9D engine at approach and take-off power. At all power settings, PK fuel produced fewer particles.

PARTICLE SHAPE -- Particle shape data shows the particle structure is more complex at climb-out and take-off than at the lower power settings. Figures 8 through 11 illustrate this effect. The effect is evident from the photographs shown in Figures 12 and 13. As an aid in interpreting the shape factor, A/P^2, Table 7 is presented. The shape factor for a disc, the two-dimensional representation of a sphere, is $\frac{1}{4}\pi$ or 0.0795. A 5-chain agglomerate has a shape factor of 0.0159; a 10-chain, 0.0078; and a 50-chain, 0.00016. Thus, as the shape factor decreases the particles are less spherical and more highly agglomerated. Generally, particles with shape factors above about 0.03 can be considered single particles trending toward a spherical shape. As shown in Figures 9 and 11, the very large exhaust particles have small shape factors and are, thus, highly agglomerated. Idle power produces relatively small particles of simple shape while climb-out and take-off power produces a wider range of particle sizes of more complex shape.

ELEMENTAL COMPOSITION -- The elemental composition of the individual exhaust particles was determined by energy dispersive X-ray techniques. No spectrum was obtained indicating the particle composition is essentially carbon.

CONCLUSIONS

The particulate matter emitted during the test cell operation of the JT8D and JT9D aircraft turbofan engines was characterized using a sampler designed expressly for this purpose. The particles are principally carbon and less than 0.1 μm in size. Particle size increases with engine power. At idle, the average geometric mean particle size was 0.045 μm and at take-off, 0.097 μm for the JT8D engine operating on JET A fuel. Particle size is influenced by the fuel composition. PK fuel with its higher hydrogen, lower aromatic, and higher smoke point content gave smaller exhaust particles. Particle shapes are more uniform and trend toward sphericity at idle; at climb-out and take-off the particle structures are more varied and complex. The mass emission rate for the JT8D engine was 0.15 kg/hr. at idle and ranged from 0.76 to 1.79 kg/hr. at take-off. PK fuel produced lower emissions than JET A fuel. Variability among the engines tested was noted. The limited data available indicate the JT9D produces less particulate matter than the JT8D. Particle concentration data show approximately an order of magnitude difference between the JT8D and JT9D engines.

The results indicate that the sampler provides a valid sample of the particles present at the exhaust plane of aircraft turbine engines.

ACKNOWLEDGEMENT

The work reported was sponsored by the United States Department of Transportation - Federal Aviation Administration under contract DOT-FA75-WA-3722. The assistance of Messrs. Paul Campbell and Ralph Johnson of United Airlines and Dr. Donald Fenton of New Mexico State University is gratefully acknowledged.

REFERENCES

1. D.L. Fenton, "Turbine Engine Particulate Emission Characterization", Phase I Report to Federal Aviation Administration under Contract DOT-FA75-WA-3722, Report No. FAA-RD-76-141, September 1976, National Technical Information Service, Springfield, Va. 22161.

2. D.L. Fenton, E.W. Nordstrom, E.H. Luebcke, "Turbine Engine Particulate Emission Characterization", Phase II Report to Federal Aviation Administration under Contract DOT-FA75-WA-3722, Report No. FAA-RD-77-165, October 1977, National Technical Information Service, Springfield, Va. 22161.

3. A.J. Fiorentino, et al., "Evaluation of Federal Aviation Administration Engine Exhaust Sampling Rake", Final Report, PWA-5534, United

Technologies Corp., East Hartford, Conn., NASA Contract No. NAS3-19447, June 1977.

4. M.B. Ranade, "Sampling Interface for Quantitative Transport of Aerosol", Report to Environmental Protection Agency under Contract 68-02-0597, December 1973, Environmental Protection Agency, Research Triangle Park, N.C. 27711.

5. M.B. Ranade, "Sampling Interface for Quantitative Transport of Aerosol", Report to Environmental Protection Agency under Contract 68-02-1295, July 1976, Environmental Protection Agency, Research Triangle Park, N.C. 27711.

6. D.L. Fenton, E.H. Luebcke, E. Nordstrom, "Physical Characterization of Particulate Material from a Turbine Engine", Department of Mechanical Engineering, New Mexico State University, Las Cruces, New Mexico. Paper to be presented at the ASME Gas Turbine Conference and Product Show, San Diego, Ca., March 12-15, 1979.

7. G.J. Sem, "Design and Application of an Electrical Size Analyzer for Submicron Aerosol Particles", Thermo-Systems, Inc., 2500 N. Cleveland Ave., St. Paul, Mn. 55113. Presented at the 21st Annual Instrument Society of America Analysis Instrumentation Symposium, Philadelphia, Pa., May 6-8, 1975.

Table 3 -- Significant Fuel Analytical Data

Analysis	JET A	PK
Hydrogen Content, %	13.05-13.65	14.25
Aromatic Content, %	17-20	1
Naphthalene Content, %	1.6-2.5	0.1
Olefins Content, %	1-2	1
Smoke Point, mm.	20-21	35

Table 4 -- Primary Air Flow as a Function of Engine Power

	Primary Air Flow (kg/sec)	
Power Setting	JT8D	JT9D
Idle	16	30
Approach	33	62
Cruise	50	82
Climb-out	62	99
Take-off	69	111

Table 5 -- Particle Size of JT8D Emission as Obtained by Electron Microscopy

Operating Mode	Geometric Mean Particle Size, μm[1]		Effect of Fuel on Geometric Mean Particle Size, μm	
	Range	Aver.	JET A	PK
Idle	0.042-0.052	0.045	0.042	0.032
Approach	0.054-0.086	0.068	0.067	0.043
Cruise	0.069-0.092	0.078	0.092	0.079
Climb-out	0.049-0.096	0.078	0.088	0.075
Take-off	0.060-0.099	0.084	0.097	0.077

[1]JET A fuel

Table 6 -- Particle Size of JT9D Emission as Obtained by Electron Microscopy

Operating Mode	Geometric Mean Particle Size, μm[1]		Effect of Fuel on Geometric Mean Particle Size, μm	
	Range	Aver.	JET A	PK
Idle	---	0.041	---	---
Approach	0.047-0.054	0.051	0.054	0.054
Cruise	---	0.041	---	---
Climb-out	0.040-0.084	0.056	---	---
Take-off	0.077-0.117	0.097	0.077	0.050

[1]JET A fuel

Table 7 -- Particle Shape Characterization

No. of Particles in Agglomerate Chain	Aspect Ratio l/d	P/d Ratio	Shape Factor A/P^2
1	1:1	3.14	0.0795
3	3:1	9.42	0.0265
5	5:1	15.7	0.0159
10	10:1	31.4	0.0078
50	50:1	157	0.00016

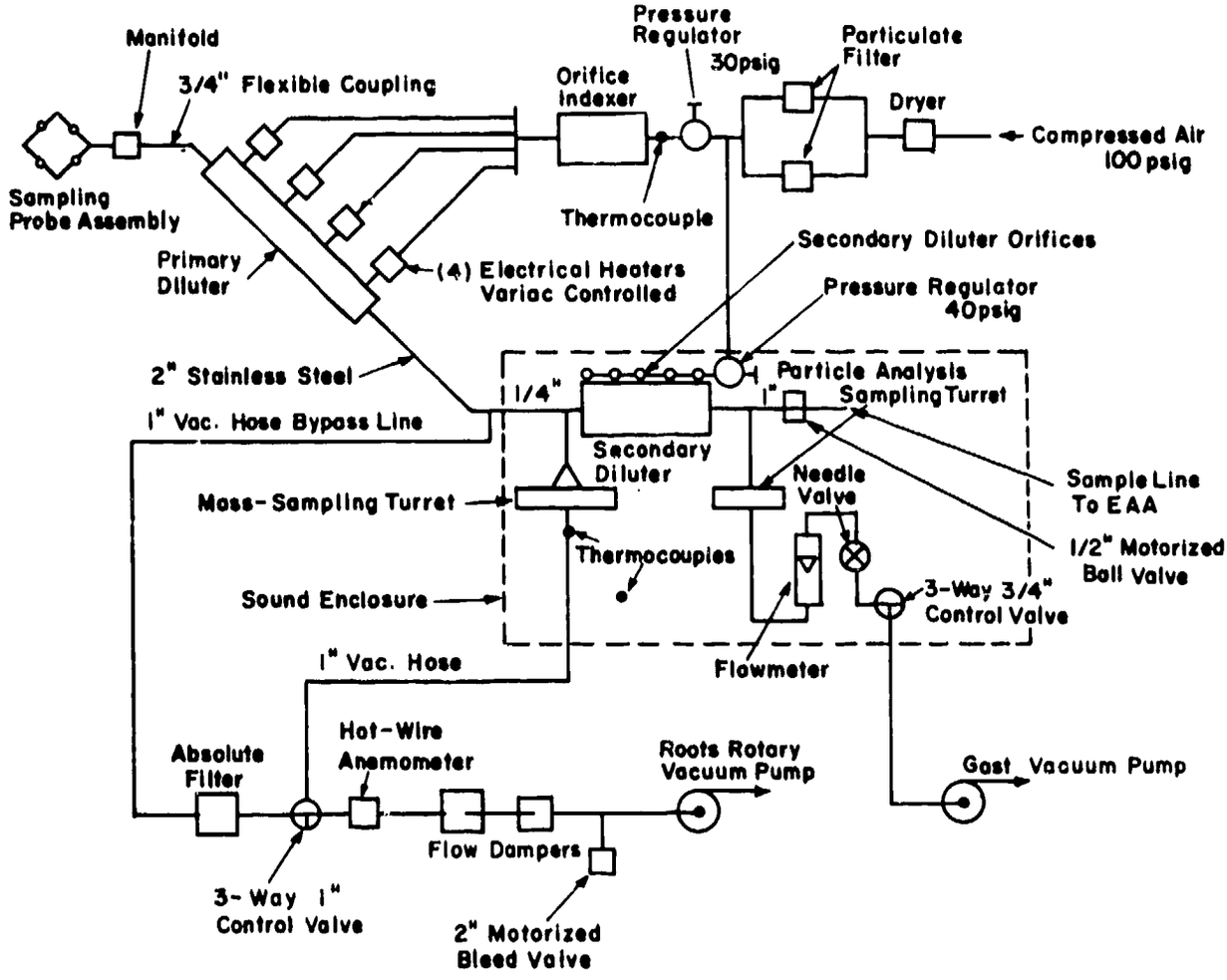


Fig. 1 – Schematic diagram of the engine exhaust particulate sampler

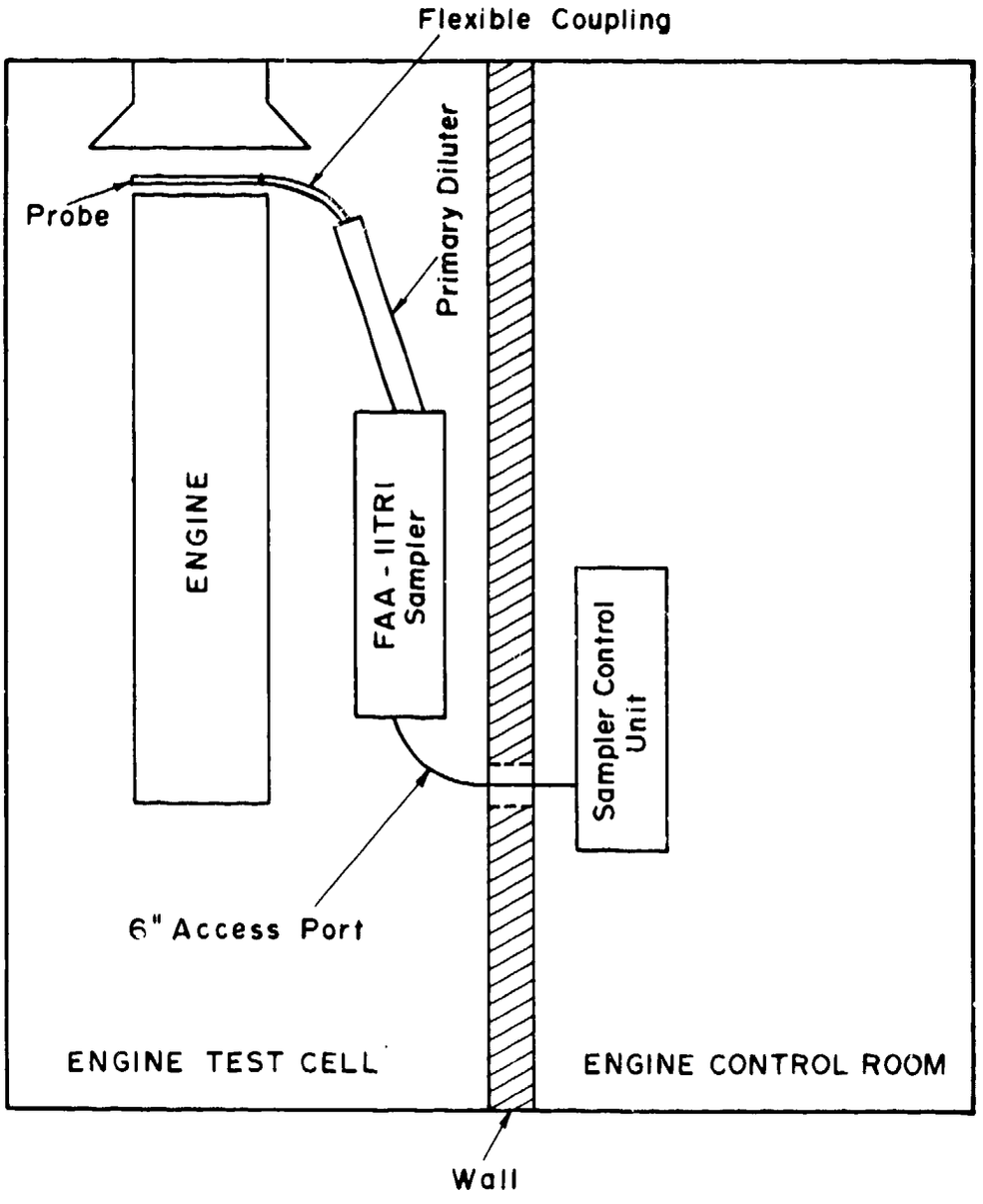


Fig. 2 – Typical layout for FAA – IITRI sampler in an engine test cell

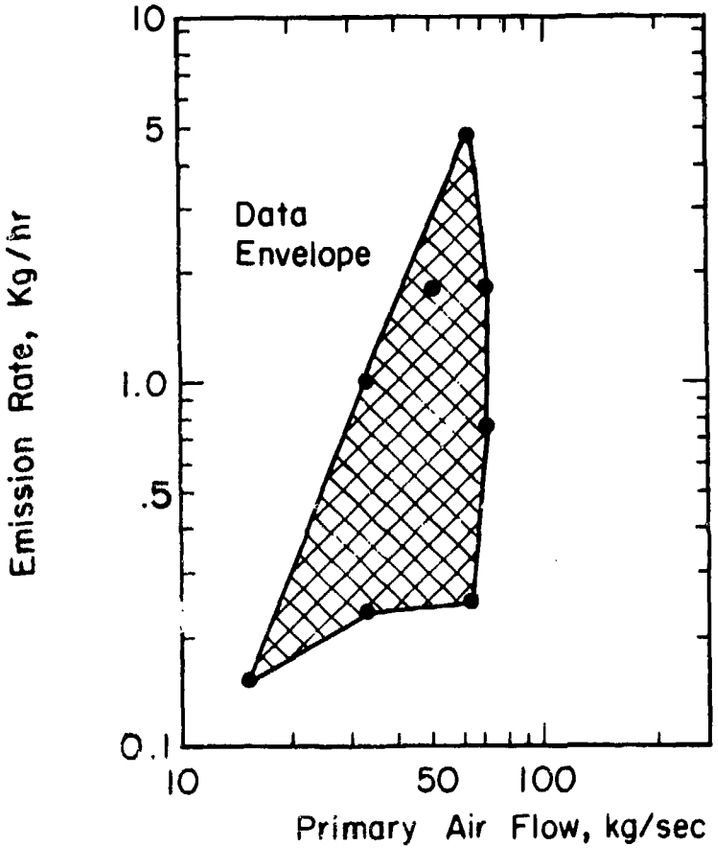


Fig. 3 – Mass emissions for JT8D JET A fuel

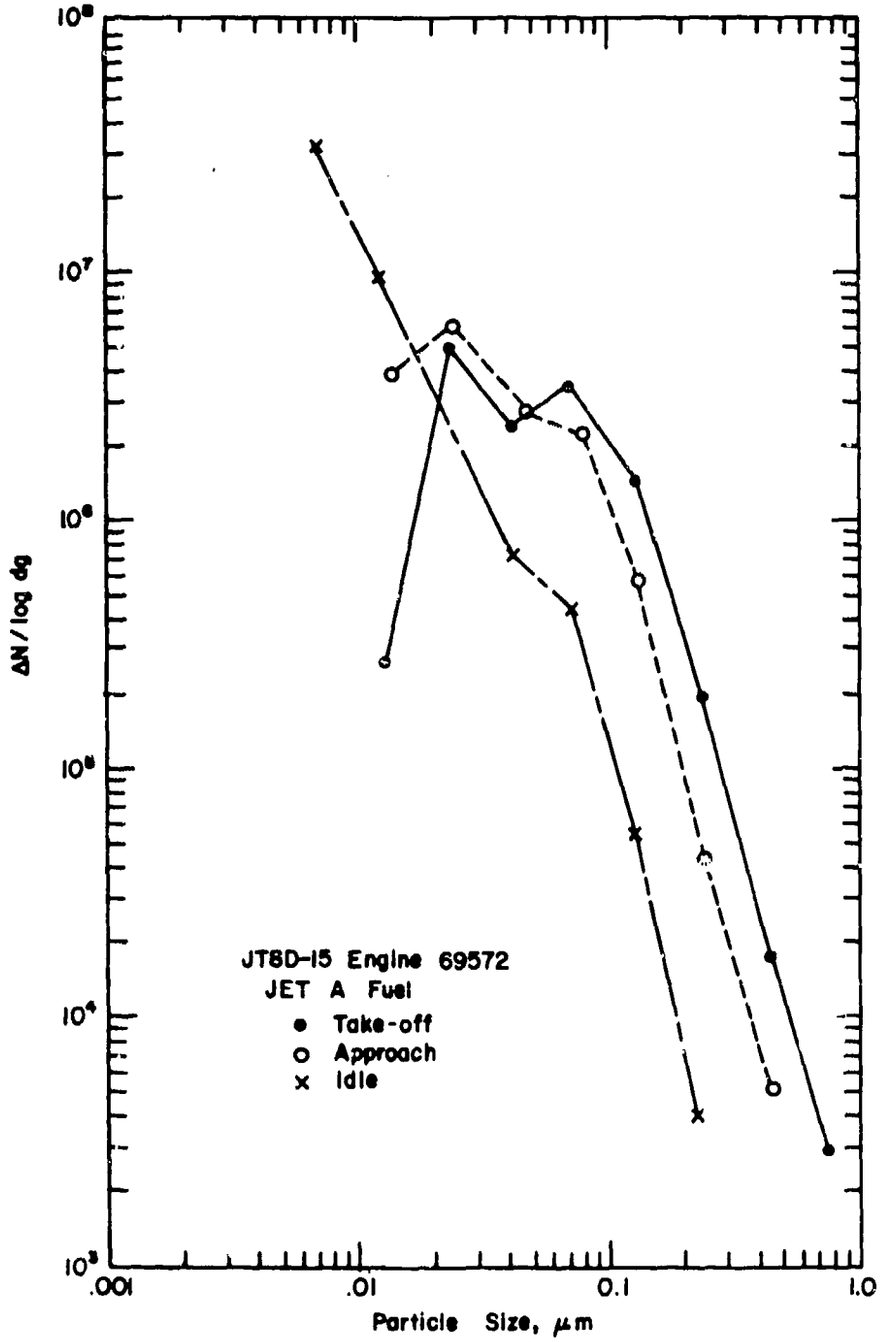


Fig. 4 - EAA particle size data for the JT8D engine

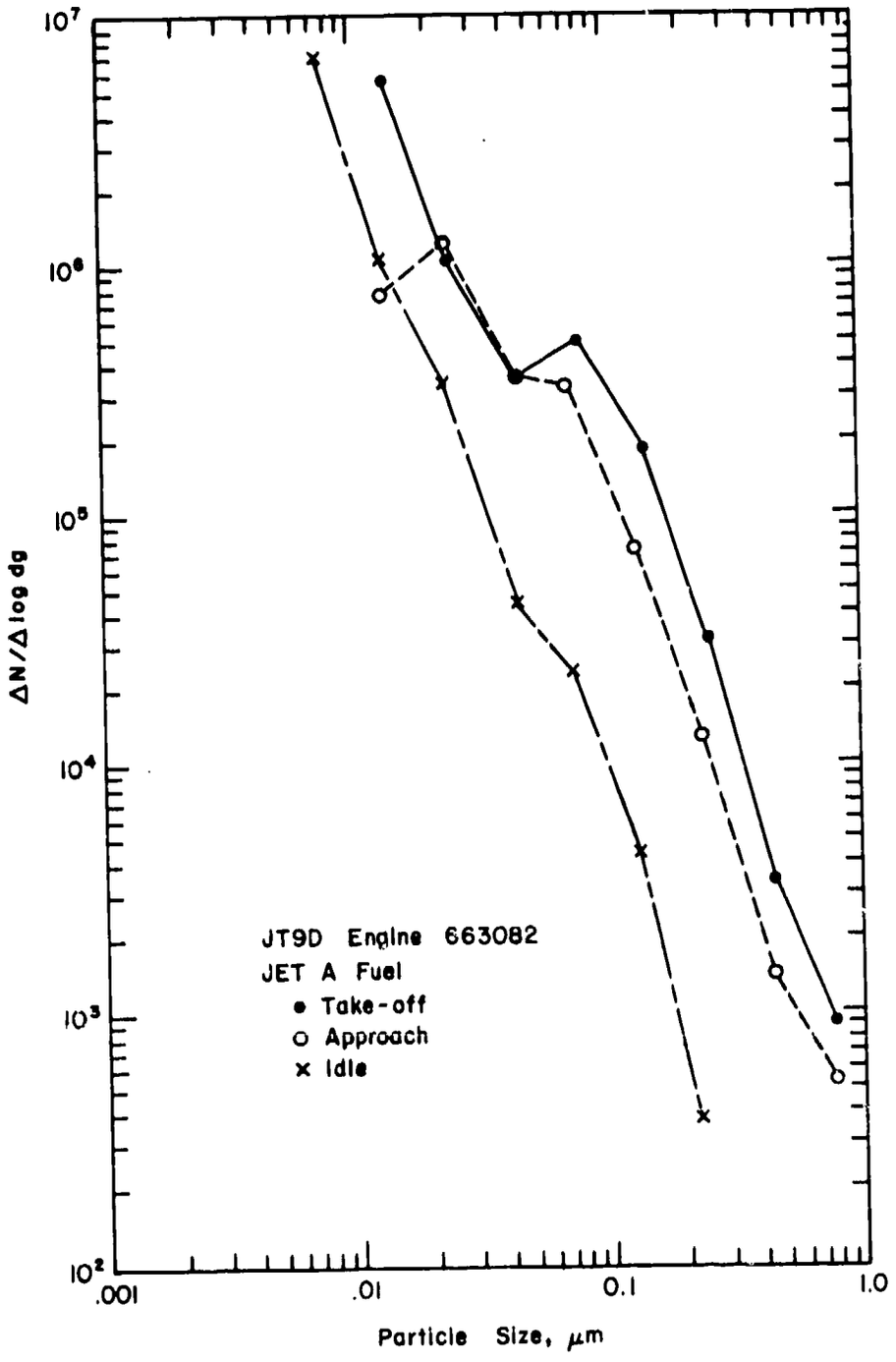


Fig. 5 – EAA particle size data for the JT9D engine

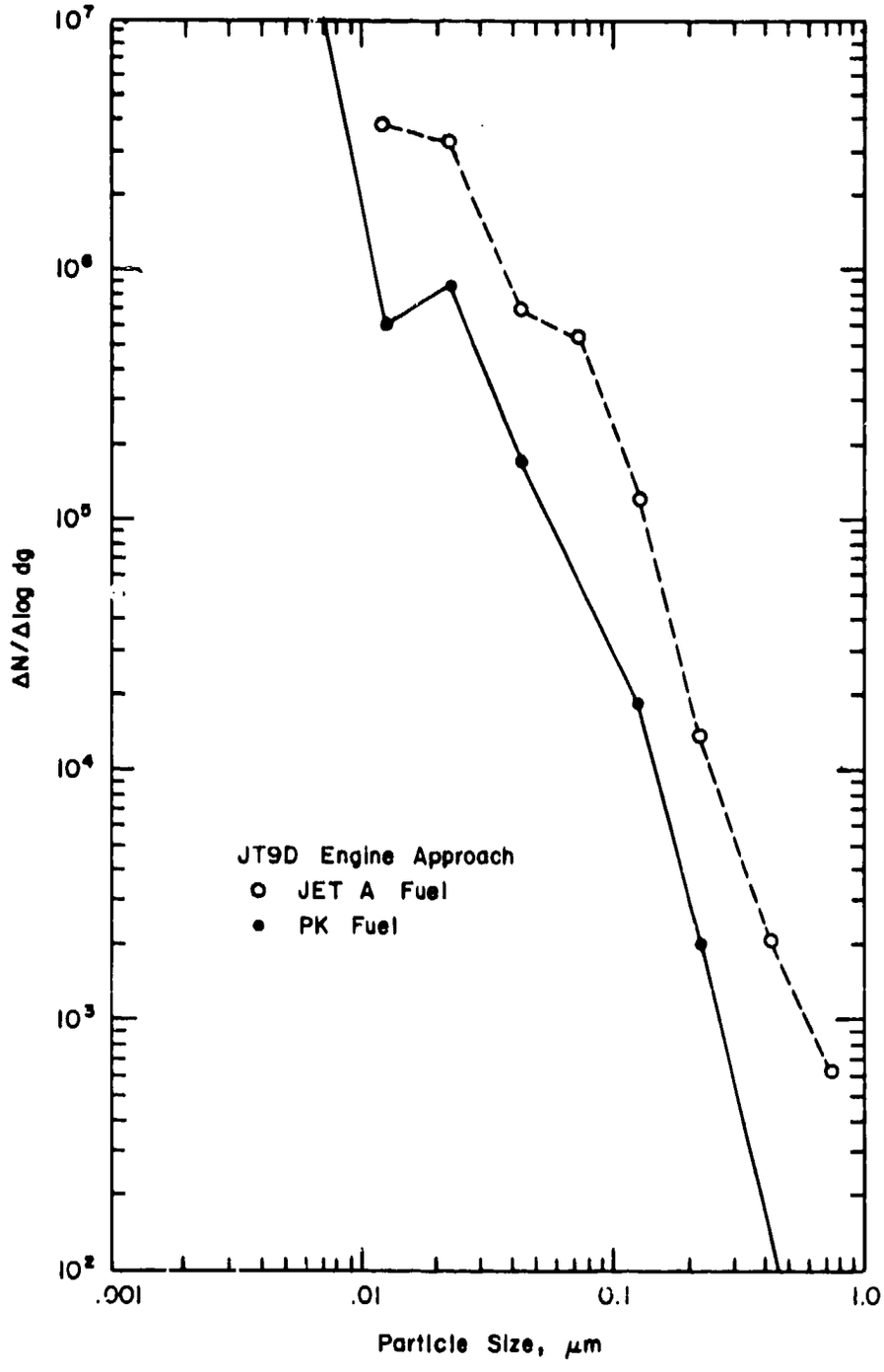


Fig. 6 — Effect of fuel on particle size of emissions

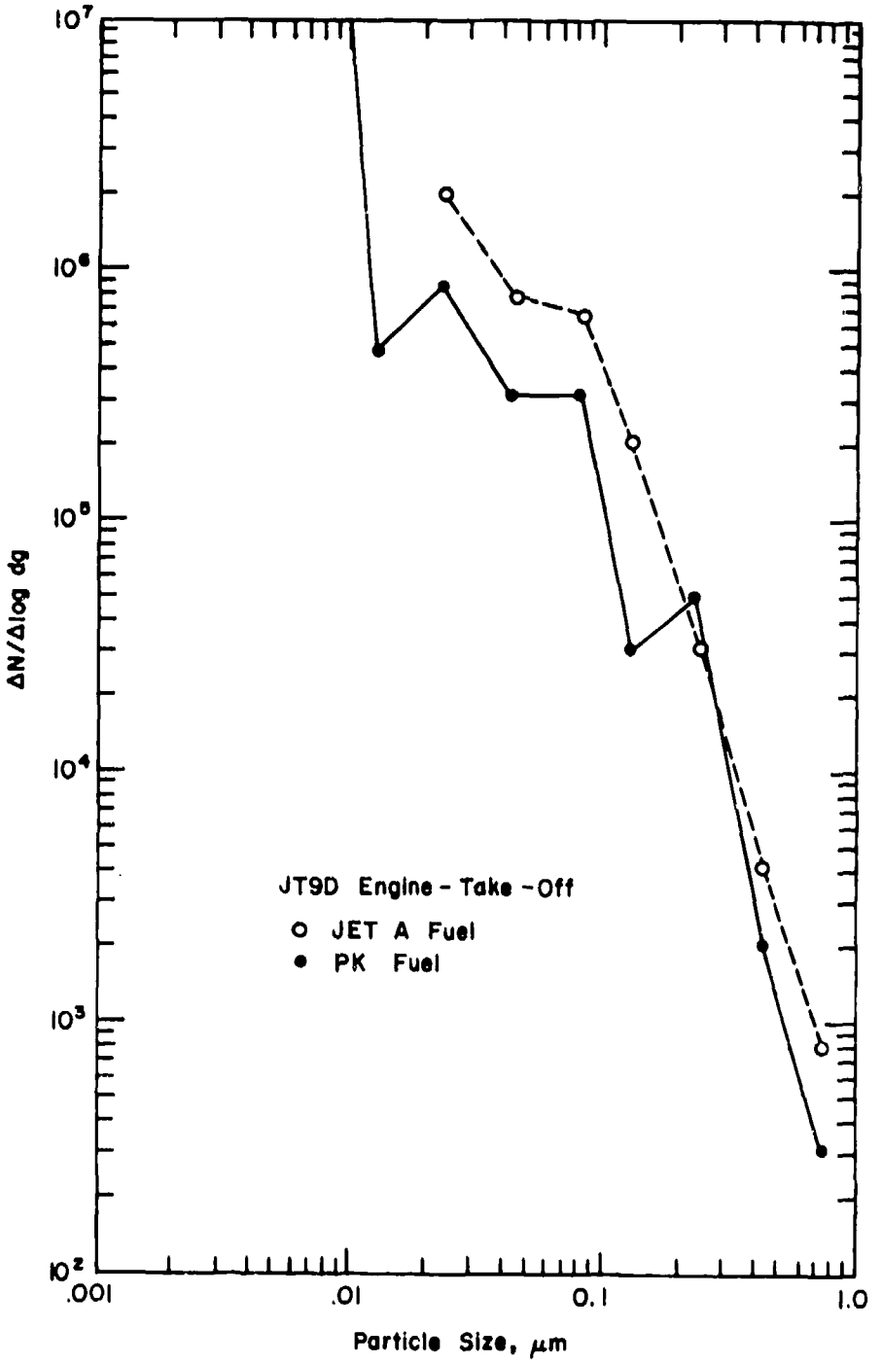


Fig. 7 – Effects of fuel on particle size of emissions

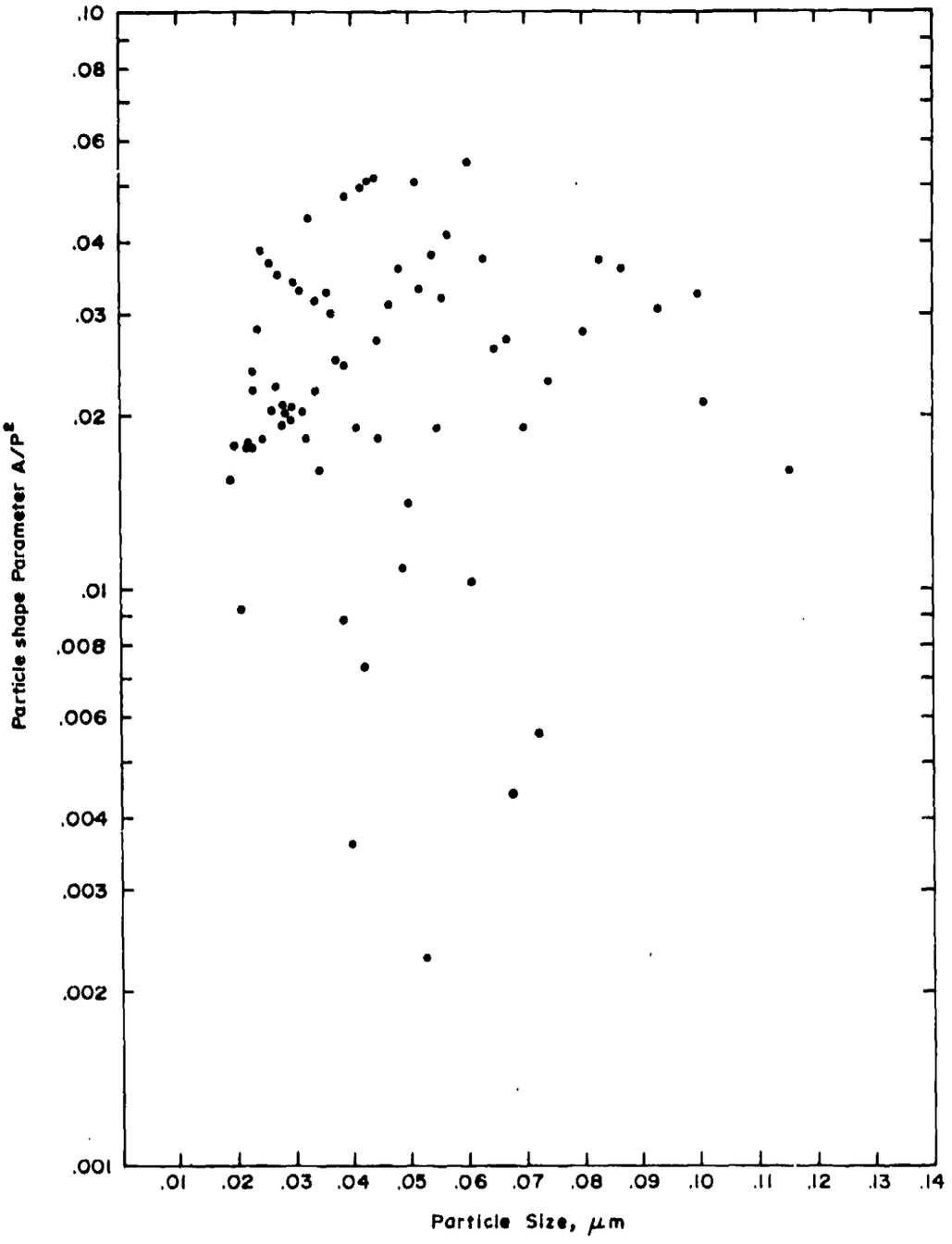


Fig. 8 - Particle shape factor, JT8D engine, idle, JET A fuel.

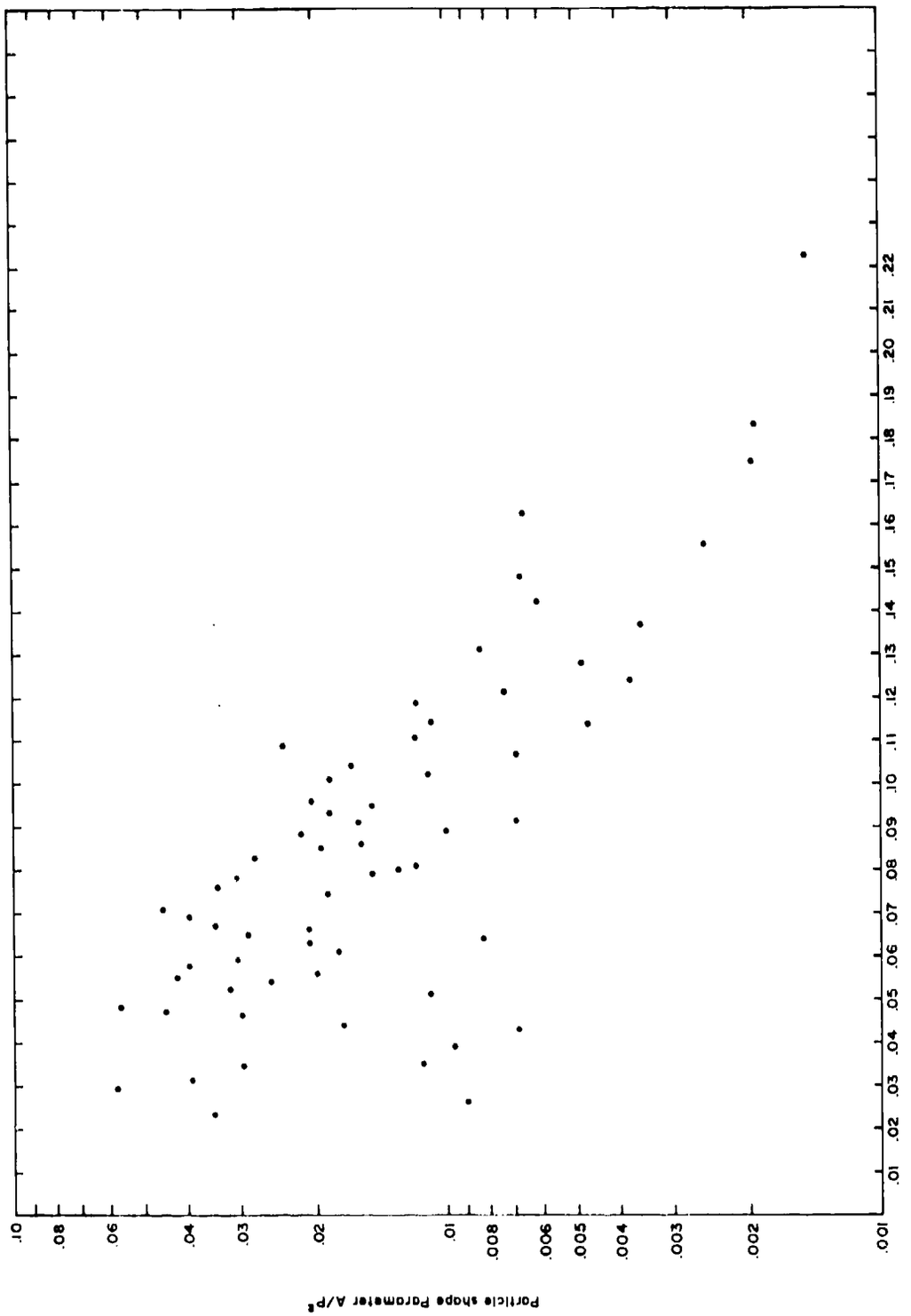


Fig. 9 - Particle shape factor, JT8D engine, take off, JET A fuel

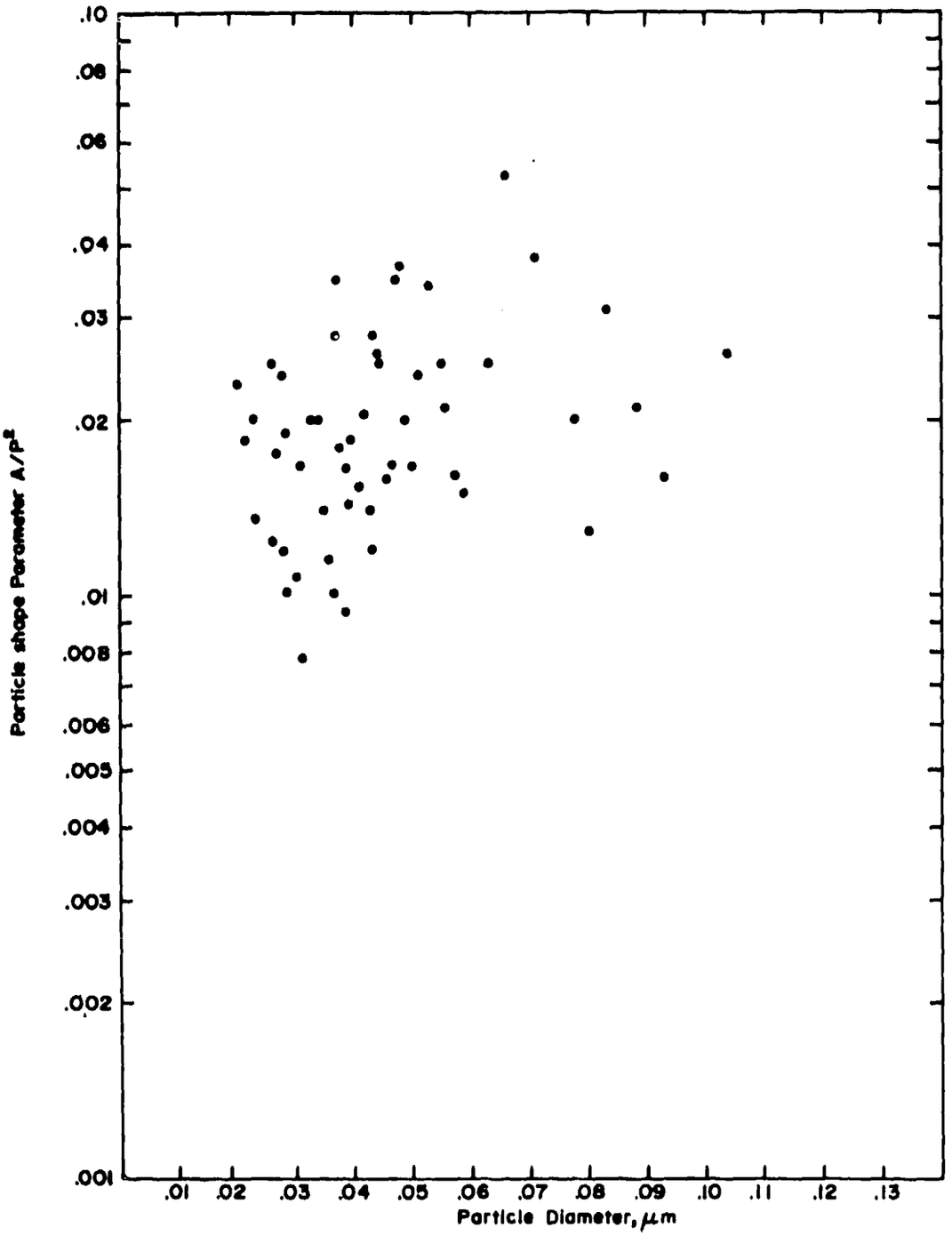


Fig. 10 - Particle shape factor, JT9D engine, idle, JET A fuel

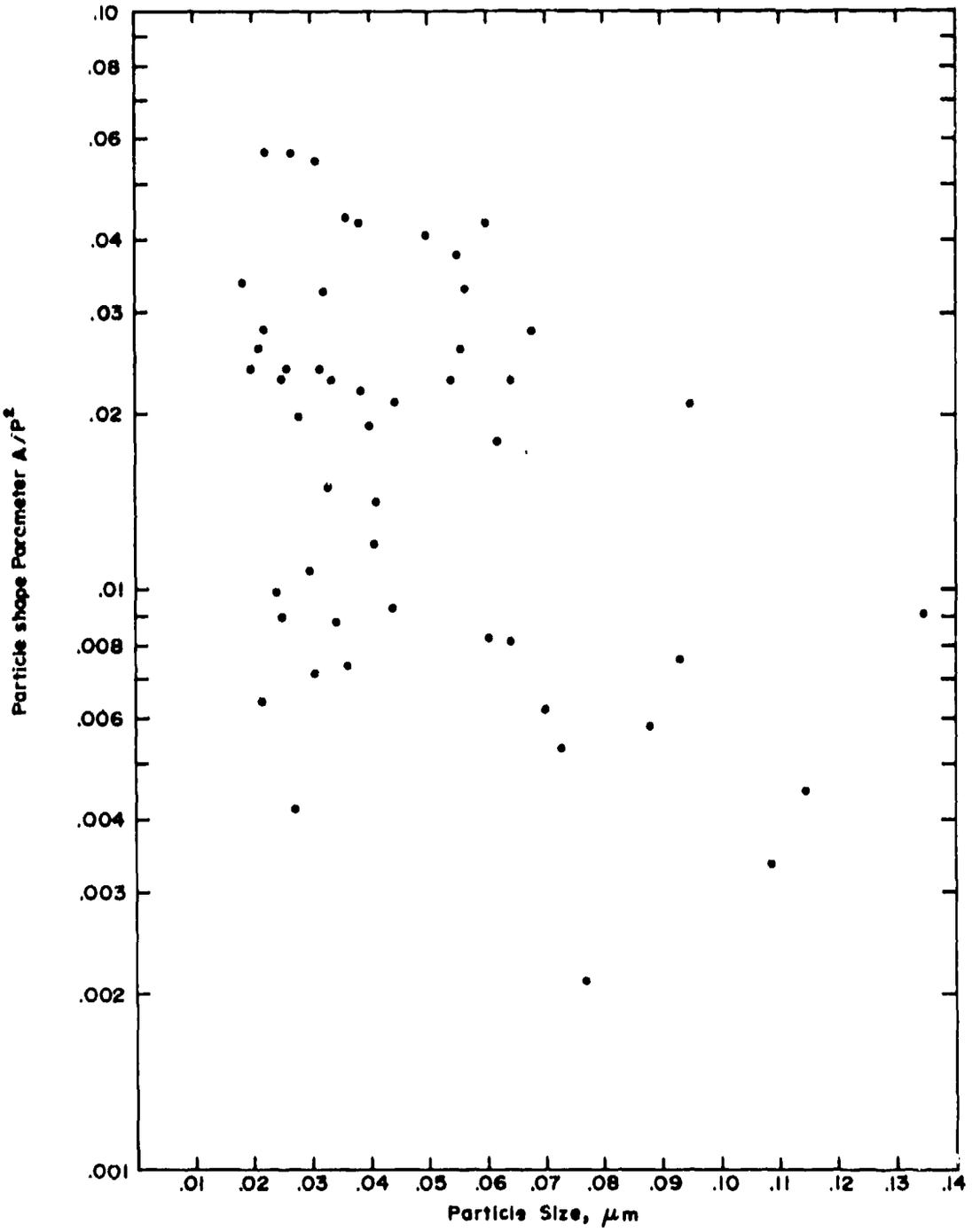
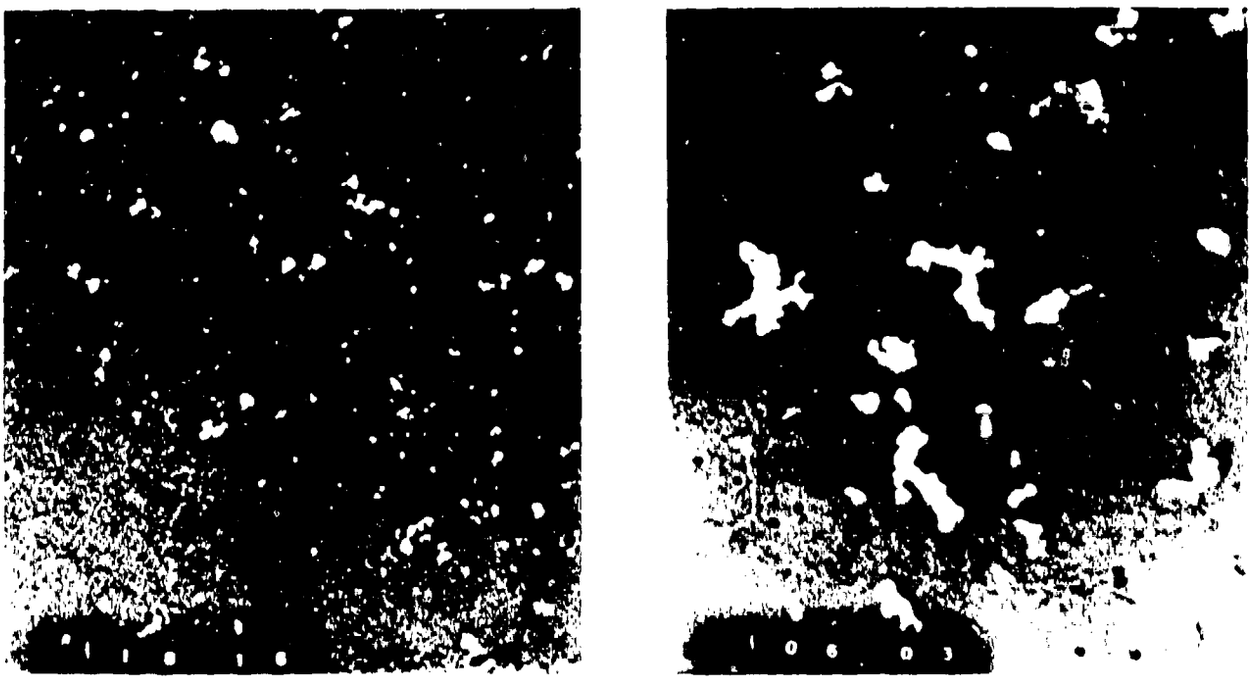
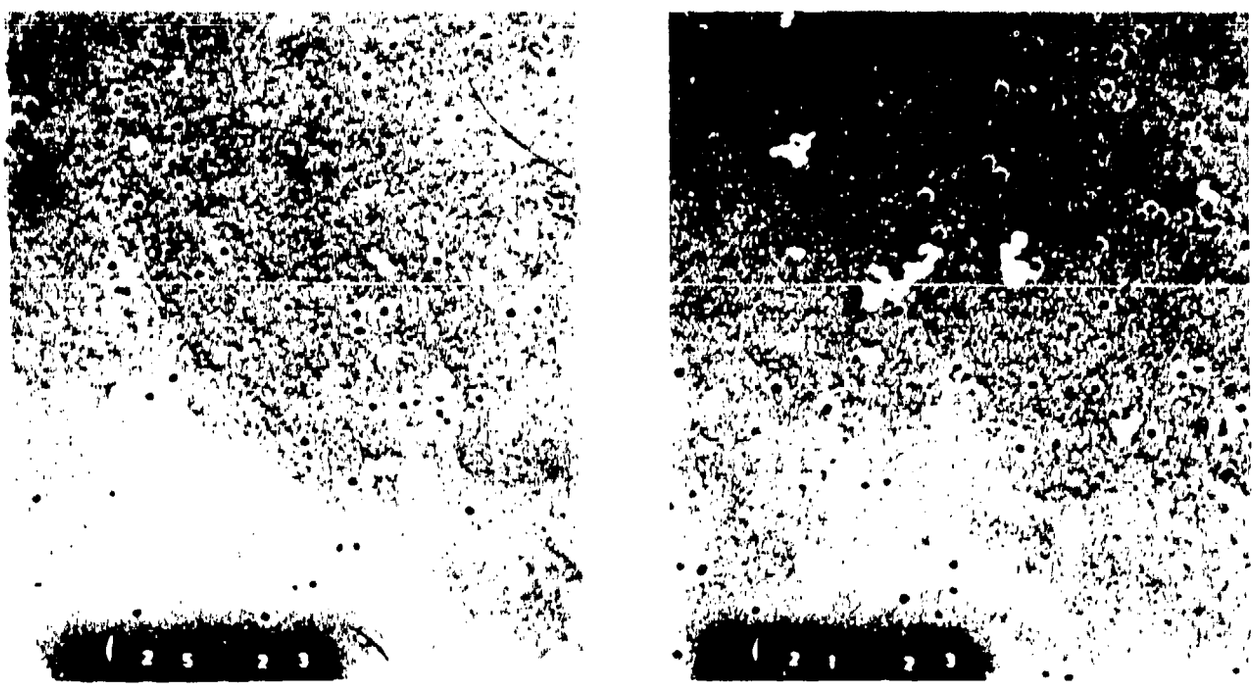


Fig. 11 - Particle shape factor, JT9D engine, climb out, JET A



Idle Cruise

Fig. 12 Particulate Emissions, JT8D engine, JET A fuel



Idle Climb-out

Fig. 13 Particulate Emissions, JT9D engine, JET A fuel

DISCUSSION

KITTREDGE: I might mention that the general subject of particulate emissions from engines is beginning to assume larger importance in the eyes of our Agency (EPA) than it perhaps has in the past.

I am thinking more at this point of diesel engines and aircraft gas turbines.

DALEY: I notice that the slides of your photomicrographs showed what appeared to be rather large, irregular-shaped particles. The pore size, you said, was 0.3 microns, I believe.

STOCKHAM: 0.03.

DALEY: The particles were many, many (10 to 20) times the size of the pore size, which would make the particles that we were looking at 0.3 to 0.6 microns.

This doesn't seem to fit, and I thought maybe you could explain that. Secondly, in combustion aerosols we usually have seen spherical chains, as you described in the later portion of the talk, and in the photomicrographs we saw rather large agglomerates, irregular shaped.

I didn't see any, or very few, spherical-shaped particles. Thirdly, was the aerosol electrically neutralized before it was passed through the aerosol collection system in the cell to the EAA outside the cell?

STOCKHAM: No, we did not electrically neutralize the aerosols that passed through.

It went through the double dilution stage and then into the EAA. Whether aerosols should be neutralized should probably be considered in some additional work.

DALEY: What was the line diameter?

STOCKHAM: I don't recall.

DALEY: Did you have any comment on the first part of the question with regard to shape?

STOCKHAM: It is quite possible that the photographs don't show some of the smaller particles. We probably picked photographs that show some of the larger particles, rather than the 400 or so particles that we did analyze.

ROTE: I am curious about the fact that the particle size, or at least the agglomeration size, seems to increase with thrust setting. Do you understand the mechanism for this, and is there the possibility that your sampling technique may be partially at fault for that?

STOCKHAM: There are always questions on how best to accomplish the sampling.

There is a greater concentration of particles at the higher thrust setting, which would certainly give these fine particles an additional time to agglomerate. That would lead to larger particle size.

One of the bases for designing the sampler was to have as short a sampling line as possible, so that there wouldn't be agglomeration, sedimentation, and such in the sampling lines.

We decided early on that we would like to locate the sampler as close to the engine as possible and have short sampling lines rather than, say, move it outside of the test cell and have a long sampling line.

The design of the sampler included taking the material as near as possible to the engine and diluting it to reduce the particle concentration. We also reduced the temperature, and thereby mitigated the agglomeration during the rest of the transport to the collector. We considered all those points, and we hope we solved some of them.

ROTE: Did you do any wind tunnel studies? I am particularly interested in the design of the sampling ports, and the possibility that at higher thrust settings (I presume that you're sampling isokinetically and went to higher velocities through that port) you increased the lateral velocities at the entrance point, and therefore increased the possibility of producing agglomeration right at the port.

STOCKHAM: There weren't any wind tunnel studies. Just the information available in the literature on that subject was considered. There are ten diameters upstream and things like that in the design.

MODELING MOBILE GROUND-SOURCE EMISSIONS AT AIR BASES AND AIRPORTS

Richard C. Sandys, Traffic Systems Consultant

Post Office Box 661, Menlo Park, California

ABSTRACT

This paper discusses models used to predict mobile ground-source emissions from vehicular traffic, which, in some cases, account for a major proportion of the air pollutants generated at an air facility. Air quality models and their sensitivity to various input parameters are considered, and recommendations are made for improving the data inputs to the models to allow for more accurate predictions.

Typical accuracy ranges, for a three-phase traffic-emissions-dispersion model are ± 30% for pollutant dispersion. Input parameters include street capacities, trip demand, intersection capacity, average speed, vehicle volumes, vehicle age, vehicle type, ambient temperature, wind speed, wind direction, and air stability. A table showing the effects of errors in input data on the traffic assignment and emissions phases of a typical model is presented.

REGULATIONS PROMULGATED to enforce the National Environmental Policy Act of 1969, require the maintenance of air quality standards for the pollutants CO, HC, and NO_x (1).* Mobile sources (which the EPA designates as "indirect sources", make major contributions to CO, HC, and NO_x pollution. Airports and air bases are included in the category of "indirect sources", and as such are required to submit environmental impact statements (EIS) to local and state authorities when building or expanding a facility. An EIS evaluates the effect of expansion or new construction on air-quality and indicates whether air quality standards will be violated because of such construction. Models are being used extensively to predict air quality at or around indirect sources. At an air base or airport, pollutants are generated form aircraft and vehicular traffic (or mobile ground-sources). Table 1 compares modeled predictions of the pollutant contribution from aircraft and from vehicular traffic. As the table indicates, vehicular traffic contributes a large proportion (sometimes more than half) of the pollutant emissions. Moreover, vehicular traffic is confined to a smaller area than is aircraft traffic, and is thus likely to produce higher local concentrations of ground-source pollutants.

Pollutant levels in the atmosphere are usually predicted by using a numerical model. Models such as AQAM (2) and ISMAP (3) are specifically designed to be applied to an air base, an airport, or other indirect source. However, such models are inherently inaccurate because they are constructed empirically to represent the average situation and because all parameters that influence results are not included

Table 1 - Comparison of Ground-Source and Aircraft Emissions

Air Base/Airport	Metric tons of Pollutants per Year					
	CO		HC		NO_x	
	Aircraft	Vehicle	Aircraft	Vehicle	Aircraft	Vehicle
Tinker AFB (4)	1000	1873*	360	160*	92	112*
Davis-Monthon AFB (4)	1600	1101*	54	94*	30	66*
Williams AFB (4)	4700	324*	1400	28*	120	19*
Dulles International Airport (6)	1569	1282	642	124	881	91
Minneapolis International Airport (7)	1136**	784	464**	67	637**	45

* AQAM Data Base (exterior network volumes are excluded) see Reference 5
** Based on average emission rate per operation found at Dulles International

*Numbers in parentheses designate References at end of paper.

in the model formulation. Thus, a user must be aware of the basic inaccuracies of a model, to compensate for them either by increasing the accuracy through calibration procedures or by using more sophisticated model components. Once an adequate model and calibration procedure have been selected, a user must determine the amount of data to be collected to run the model and the refinement necessary for those data.

Just as the user must be aware of inherent model inaccuracies he must also be aware of the effects of inaccurate data. Usually, much of a modeling effort is spent in collecting data. It therefore makes sense for the user to emphasize the collection of data to which the model is most sensitive. Model reliability and sensitivity to input data are discussed in more detail below.

MODEL RELIABILITY

Air quality modeling of mobile ground-source contributors is typically undertaken in three phases. First, a traffic network is modeled to predict volumes, speeds, and congestion on a network of streets (or links*). Second, CO, HC, and NO_x emissions are predicted for all vehicles on each street. Third, pollutant levels are predicted at receptor locations by using a dispersion submodel. A final step is required to add background concentration levels to levels predicted by the dispersion submodel. These background levels are usually based on levels monitored at nearby locations, but evidence also indicates that background concentrations should sometimes be included to account for long-range transport of pollutants.

An air quality models first step is predicting vehicular traffic on a street network. Street traffic volumes can generally be predicted to within ± 20% of actual field measurements. Problems associated with predicting such volumes include the determination of the number of trips made between areas (or zones) of the street network and the determination of the route followed by vehicles making such trips. Because an air base or airport has gates through which and access roads over which most of the vehicular traffic must travel, gate counts can be used to improve the route selection process and therefore increase the model accuracy. Traffic submodels may also be used to predict freeway congestion, intersection congestion, road speeds, and the amount of trip time within the parking lots. Results om the traffic prediction serve as input to the emissions prediction phase of the model.

A typical air quality model next predicts vehicular (ground-source) emissions. A ± 25% accuracy range has been estimated for the EPA emissions prediction model (8). In a current EPA project, the accuracy of some of the model assumptions, is being checked (9); the agency is seeking to determine the adequacy of assuming the Federal Test Procedure (FTP) driving cycle when predicting emissions near a signalized intersection. Furthermore, vehicle maintenance factors have been published to refine emissions predictions that are based on mandatory vehicle maintenance performed in an area being modeled.

*A "link" represents the flow of traffic in one direction on a street. Therefore, a street can include either one or two links.

The third step of a typical air quality model is to predict pollutant concentrations at selected receptor locations. Dispersion models are generally accurate to within 30%. Accuracy limits could rise as high as 200%, however, if an inappropriate model is used. Terrain features such as cut and fill sections of roadway (10), and street canyons (i.e., locations with tall buildings on either side of a street) (11) must be modeled with sophisticated dispersion models to achieve 30% accuracy.

The results of the dispersion phase are added to background concentrations. A recent study (9) indicates that long-range transport of pollutants under special weather conditions needs to be included in many localized models of air pollution. (e.g., CO can be transported away from a downtown section of a city by prevailing day-time wind and transported back to the city by evening air movement from the opposite direction).

SENSITIVITY TO DATA INPUTS

A user who is well aware of his model's limitations and requirements must still decide how to collect data and how much effort to expend in their collection. Although some data do have negligible effect on model results, others are crucial for accurate findings and must be collected in the field. The user therefore needs a guide to aid him in determining which data are important. Such a guide is presented in Table 2 for typical data inputs to the traffic and emissions phases of a standard model. Table 2 was created using the modeling procedures found in References 3, 8, and 12 to determine the effects of changes to input data. The table is organized with the most important input data items listed first and the least important input data items listed last--an order based on the author's estimate of the size of a typical error in the data input. The error resulting from an inaccurate input is given as a percentage change in one or more of the predicted results.

The largest error seen in Table 2 is due to an error in traffic prediction comes from "Street Delays". A 16-s error in predicting delay on an 840-ft (256 m) street where the speed is 25 mph (40 km/hr) represents a 43% error in the predicted speed. A 34% error in speed results in a 45%, 32%, and 12% error in CO, HC, and NO_x emissions, respectively. The initial 16-s error might occur because of an incorrect model of a signalized intersection; in this case field data might be used to calibrate the intersection model to eliminate the delay error.

The largest error in predicted emissions in Table 2 is due to a 30% error in the number of hot/cold starts when the ambient temperature is 30°F (-1.4°C). This case compares a situation in which 20% of the vehicles on a road are cold start with a situation in which 50% are cold start. Because the change represents a 59%, 39%, or 10% difference in CO, HC, and NO_x, it is important to know the percent of hot/cold start vehicles. But hot/cold start data are quite difficult to collect in the field. The solution appears to be the use of sophisticated model that keeps track of vehicles from the start to the finish of a trip. Then, the only data required to predict hot/cold percentages on a street are the number of cold start vehicles originating in each zone. Further detail can be

Table 2 - Model Sensitivity to Data Inputs

Traffic Prediction Phase

Data Item	Typical Error	Error In VMT (%)	Error In Speed (%)
Street delay	17 s		43
Street speeds	5 mph (8 km/hr)		20
Street capacity	15%		11
Parking capacity	10%		11
Vehicle type	4% HDT*, 1% HDD**		11
Zone trip attractions	10%	10	
Zone trip productions	10%	10	
Intersection capacity	15%		9
Vehicle load factor	8%	8	
Peak hour factor	15%	8	
Link lengths	50 ft (15 m)	6	

Emission Prediction Phase

Data Item	Typical Error	Error In CO (%)	Error In HC (%)	Error In NO_x (%)
Hot/Cold @ 30°F (-1.4°C)	30%	59	39	10
Speed	43%	45	32	12
Traicer towing	20%	45	11	6
Hot/Cold @ 75°F (24°C)	30%	29	20	10
Speed	20%	21	15	5
Number of vehicles	20%	20	20	20
Vehicle type	4% HDT, 1% HDD	18	14	16
Vehicle age distribution	10% new vehicles	15	15	7
Air conditioning	50%	9	7	9
Vehicle load	20%	4	1.2	0.6
Evaporative emissions	10% new vehicles		14	
Humidity	10%			3.5
Vehicle maintenance	---	---		

* HDT = Heavy-duty truck
** HDD = Heavy-duty diesel

included by keeping account of the number of cold start trips by trip purpose (e.g., shopping-to-home trips might consist of 10% cold starts, whereas home-to-shopping trips might consist of 80% cold start vehicles).

FORESEEABLE IMPROVEMENTS

We predict that typical model accuracy range will improve. Current studies use gate counts to improve traffic assignment, analyze the appropriateness of the FTP driving cycle when applied at intersections, and predict effects of wind deflectors to promote air circulation in canyon like structures (7). Calibration of model phases to measured values such as vehicle volume and speeds, and air quality monitoring station data can provide a user with a high level of confidence in the modeled results. Refinement of data inputs into 15-min intervals during peak travel demand, and sophisticated estimation of hot/cold start vehicles by trip purpose will provide more accurate model results. Improvements in the type and quality of model input data, such as maintaining records of the hot/cold or stabilized vehicles on each street, recording heavy-duty vehicle volumes separately, and employing special dispersion techniques for nonflat terrain should all lead to more reliable models of air quality.

REFERENCES

1. 40 CRF 51, "Preparation, Adoption, and Submission of Implementation Plans: Maintenance of National Ambient Air Quality Standards," Federal Register, June 18. 1973.

2. D. M. Rote, "A Generalized Air Quality Assessment Model for Air Force Operations," Air Force Weapons Laboratory, Kirtland Air Force Base, NM 87117 AFWL-TR-74-304, February 1975.

3. R. C. Sandys et al., "ISMAP - A Traffic/Emissions Dispersion Model for Mobile Pollution Sources," SRI International Project 6324 Report, July 1977.

4. D. F. Naugle, B. C. Grems, and P. S. Daley, "Air Quality Impact of Aircraft at Ten U.S. Air Force Bases," Journal of the Air Pollution Control Association, Vol. 28, No. 4, April 1968.

5. W. Viezee et al., "Source Emission Inventory for AQAM: Review of Field Data Collection Program," SRI International Project 4744, Final Report, June 1976.

6. E. Shelar, "Air Quality Characteristics at Dulles International Airport for 1976, 1980, 1985, and 1995," Presented at the International Air Quality and Aviation Conference of the Air Pollution Control Association and the Society of Automotive Engineers, Inc., October 16-18, 1978.

7. BRW, Inc., "Minneapolis-St. Paul International Airport - Airport Parking Expansion Program," draft Environmental Impact Statement, July 1978.

8. EPA, Office of Transportation and Land Use Policy, "Mobile Source Emission Factors - Revision to Supplement 5 to AP-42," January 1978.

9. "Characterization of Motor Vehicle Operation in Areas with Above-Standard Carbon Monoxide Concentrations," SRI International Project 6541 Interim Report.

10. W. Dabberdt et al., "Atmospheric and Wind Tunnel Studies of Near-Highway Air Pollution Dispersion," paper submitted to Technical Analysis of Air Pollution on the Local Scale, Transportation Research Board, January 16-20, 1978.

11. F. L. Ludwig et al., "Users' Manual for the APRAC-2 Emissions and Diffusion Model," SRI International Project 5338 Report, June 1977.

12. EPA, "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 9: Evaluating Indirect Sources," Report EPA-450/4-75-001, (1975).

DISCUSSION

SCHUERMAN: I was interested in Table Two. Your very last item addresses vehicle maintenance, or conversely, the deterioration of the vehicle as potentially an important factor in the emissions emitted by the ground vehicles.

I am curious to know if you have any feel for the accuracy of your model and a knowledge of the maintenance practices and what impact they have. You obviously had left those blank.

SANDYS: I left them blank because I haven't studied it very well, and I don't really know how it is going to improve the emissions modeling. No one at EPA has assured me that it is going to improve it a certain amount either.

PANOFSKY: When you write down something like 25 percent accuracy, what does that mean? Does that mean that 90 percent of the time you will be within 25 percent or does it mean half the time?

SANDYS: These were rule-of-thumb estimates made by people who have used models a lot. If the model predicts within a certain accuracy range, then they figure that they have gotten about as far as they can go with the model.

PANOFSKY: Within that accuracy range all the time or a certain fraction of the time? In other words, when you say 25 percent, does it mean in all the predictions they made they were within 25 percent or does it mean something less stringent than that?

SANDYS: A little less stringent than that. It means that they just accept the fact that that might be about 25 percent off.

PASQUILL: I didn't entirely get clear on what basis you made the assessment of the dispersion modeling accuracy. After all, 30 percent in dispersion modeling is very accurate, and I wondered on what basis you actually assessed that accuracy.

SANDYS: I talked to some people at SRI who have had modeling experience. Frank Ludwig gave me the figure. He thought that was pretty much what he could do with a good model where the wind wasn't veering too much and conditions were fairly reasonable over the period of time being modeled. When you don't have reasonable conditions, where there are a lot of streets or buildings, the 200-percent figure might apply.

Would you have another input to that figure?

PASQUILL: I wasn't quite sure whether this was a general figure that somebody proposed to you or whether you actually had some data on which you made that assessment. I think the answer is it is the former, isn't it?

SANDYS: Right. It is a rule of thumb, but it would be interesting to hear yours. Do you have another one?

PASQUILL: Well, I did attempt some estimates, on the sort of accuracies that you could achieve, according to the circumstances of source, emissions, and meteorological conditions, and they are written down in a paper, to which I can give you a reference.

It turns out the more ideal the conditions of the experiment, the source and the meteorological conditions, of course, the better the accuracy and vice versa.

NAUGLE: Given the problem of trying to predict the impact of vehicular operations around air terminals, would you feel fairly comfortable in applying your vehicular models or would you suggest that perhaps the inaccuracies are such that we might be better off going to solely a measurement program in the terminal areas of airports?

SANDYS: I think that the models are pretty good, except that they are not sensitive enough in the areas where there is a loading and unloading zone at the airport or in an area where there is quite a bit of congestion, or where there is an unusual circumstance.

As far as I know, there is no good model for the passenger loading and what goes on as far as waiting times, the number of vehicles idling, and the building configurations in the particular facility.

I don't think that the model is available right now.

NAUGLE: Would you agree that any measurement study might also suffer from the same problems and that you might measure some air quality in the area, but you wouldn't know how to relate it to some vehicular traffic pattern?

SANDYS: Right. Once you measure the air quality, you still don't know how to predict it when you don't exactly know why you have the numbers you have.

ROTE: Dr. Ken Brubaker and I just finished a chapter in a book on modeling of sulphur dioxide in urban environments, and I can comment on what we found in that regard. We reviewed a large number of studies that have been done on sulphur dioxide modeling in urban areas, and you should keep my comments within that context.

Sulphur dioxide, you recall, is a much easier pollutant to obtain an emission inventory from, as you have a lot of engineering guidance in that respect. We find that if you are computing annual averages of sulphur dioxide concentration, you can obtain concentrations within plus or minus 20 or 30 percent.

That is an annual average for SO_2 in an urban area. That means, though, that you have a pretty good handle on the meteorology, you have a rather straightforward meteorological environment, and you have a very good handle on the emission inventory.

If you just go into an urban area and take somebody's emission inventory from a NEDS file, you can easily be off by 50 or 100 percent. But if you do a good job in emission inventory, you may achieve plus or minus 20 percent for annual averages.

TESCHE: The tables you showed indicating model sensitivities strike me as being very interesting. Have you looked at any of the costs associated with preparing certain of those emission model inputs and tried to rank order the costs in relationship to the importance to the overall performance of the air quality model?

SANDYS: Yes, but I haven't done that type of study at all. Are you involved in that at all?

TESCHE: No, but I am interested in it.

SANDYS: We might talk about the data sources just to identify that. There are different means of collecting all of the data inputs to the model, so you can go into a more-or-less detailed method, and I think you have to choose what method you are going to use based on how much money you have and how much accuracy you need.

UNIDENTIFIED: I took a look at Table One on your ground source and aircraft emissions, and, just looking at some of the numbers there, I find something surprising: the aircraft-to-vehicle emission ratios at Williams were two orders of magnitude larger for CO and NO_x and two orders of magnitude larger for hydrocarbons.

This really surprised me. Is this a function of operation of the base or the assumptions used?

SANDYS: These were modeling results that I used, and they were the results of the AQAM model that the Air Force has developed.

According to the people who developed the data for the various bases, the fighter planes at the small bases apparently emit a high number of pollutants for the size of the aircraft, and then they do a great deal of takeoffs and landings.

They are training flights, so they fly all day long. It is a matter, I guess, of intensity of traffic.

UNIDENTIFIED: Do you believe these numbers?

SANDYS: I used this table to try to point out the need for the vehicular traffic assessment because it is almost as big a problem as the aircraft problem. I just wanted to show that the vehicular traffic is a very important element of the emissions system.

CHARACTERIZATION OF AEROSOLS AT AN AIRPORT

D. C. Woods, K. H. Crumbly, and R. W. Storey,
NASA Langley Research Center

and

F. S. Harris, Jr.
Old Dominion University

ABSTRACT

The aerosols in an area of heavy aircraft traffic were characterized in terms of the average daily mass loading, the variation in mass loading with time of day, the size distribution, and the elemental composition. The air was sampled continuously with a high-volume sampler with 24-hour sampling periods, 47-millimeter Nuclepore filters with 2-hour sampling periods, and an 8-stage Andersen impactor with 24-hour sampling periods. Selected filters were analyzed by neutron activation analysis and proton-induced x-ray fluorescence to determine elemental composition as a function of time of day and as a function of particle size.

INTRODUCTION

The Langley Research Center, in cooperation with the Virginia State Air Pollution Control Board (SAPCB) Region VI, has participated in several regional air quality studies at various locations in the Norfolk, Virginia area. In August 1973, a 2-week aerosol characterization study was conducted near downtown Norfolk.[1] A similar study was made at the Norfolk Naval Air Station (NAS) during July and August 1974, and a third one during the summer of 1975 was conducted in the Chesapeake area. The objectives of these studies were to evaluate the possible application of instrumentation and technology developed under other NASA programs to environmental problems while at the same time assisting the SAPCB in establishing a data base throughout the region.

In this paper selected data from the second study (NAS 1974) are presented. The measurements were made near an active runway at NAS and focused specifically on particulates with no gaseous species being measured. The objective was to characterize the particulates at this location in terms of the average daily mass loading (mass concentration), the variation in mass loading with time, the elemental composition, and the size distribution. Because of the air traffic at NAS a secondary objective was to assess the impact of the aircraft operations on the air quality. A variety of instruments was employed initially in the experiment, however, because of a number of instrument malfunctions, operational problems associated with the rainy weather, and the fact that some of the data were not fully analyzed, only selected data are presented herein. The data presented can serve as an adequate data base for comparisons with measurements made in other locations and future measurements at NAS.

LOCATION AND SURROUNDINGS

The location and physical layout of NAS and surroundings are shown in Figure 1. The mobile laboratory used in the experiment was located about 90 meters north of the east end of the major runway and is indicated by X on the map. The sampling station was not located near any of the major roadways on the base, therefore, the contribution from auto traffic was not expected to be high. About two-thirds of the base is surrounded by water and the remainder is bordered by residential and limited commercial areas. There were no major industrial operations within several miles of the base.

There were on the average about 165 takeoffs or landings on the runway each day with a variety of aircraft types. Most of this activity was during the daylight hours. In addition to the aircraft activities, there were several jet engine static test cells about 2 miles northwest of the primary sampling station, which operated occasionally for short periods (several minutes). During their operation the effluents were highly visible but no immediate effects were noticed on the sampling instruments.

INSTRUMENTATION

All of the instruments employed in the study are listed in Table 1. The type of data generated and their time resolutions are also listed. Data obtained with the Nuclepore filters, high-volume filters, and Andersen cascade impactor are presented in this paper. Because of instrument problems, operational problems and incomplete analysis, no data from the other instruments will be presented.

TABLE 1

Instrument	Type of Data	Time Resolution
Nuclepore filters	Mass loading/ elemental	2 hour
High volume sampler	Mass loading	24 hour
Andersen impactor	Size distribution/elemental	24 hour
Royco light scattering photometer*	Number concentration	10 minutes
Integrating nephelometer*	Extension coefficient	2 seconds
Lundgren impactor*	Mass loading/ size/elemental	
Quartz crystal microbalance*	Mass loading	10 minutes

* Data not presented in this paper.

PROCEDURE AND RESULTS

The measurements were started on July 25, 1974, but were interrupted from August 6 through August 18 because of rainy weather and instrument malfunctions. The measurements were resumed on August 19 and continued through August 27, 1974.

Nuclepore Filter Measurements. Particles were collected on 47-mm diameter polycarbonate membrane filters using an automatic sequential timing arrangement in which each filter in a 12-filter linear array was sampled for 2 hours. With this arrangement the air was sampled continuously for 24 hours a day with 2-hour time resolution in the measurements. The air was pulled through each filter, which had a 0.4-micrometer pore size, by a small mechanical pump at a volume flow rate of approximately 0.028 cubic meters per minute. The flow was monitored continuously with a recording flow meter. Each filter was weighed before and after exposure in a class 100 clean room with controlled humidity at Langley Research Center, following the procedure described in Reference 1. The mean mass loading (mass per unit volume) was determined for each 2-hour time interval from the total mass of particulates collected on the corresponding filter and the volume of air sampled.

Figures 2a and 2b show plots of mass loading as a function of time of day over 24-hour periods from midnight to midnight for July 26, 1974 through August 3, 1974. The same type of plots are shown in figures 2c and 2d for the period of August 21, 1974 through August 27, 1974 when the sampling was terminated. Each data point is located at the midpoint of the 2-hour sampling period and represents the average concentration for that period. The mass loadings varied widely over the 24-hour periods and also from one day to another. This variation was not periodic in that the highs and lows did not always occur at the same time of day. However, the concentrations were in general higher during the daytime hours than at night. Any contributions from aircraft activities are combined with the ambient and are not separable by the filter data available. The EPA limit of 260 micrograms per cubic meter over a 24-hour period was not exceeded for any of the days on which data were collected. While some individual excursions are relatively high, they are within the range of values measured near downtown Norfolk in August 1973 (Ref. 1). The wind directions were monitored continuously and there was no apparent correlation of mass concentration of wind direction. This rules out the possibility of pinpointing a single source as a primary contribution on the basis of wind directions in the case of these measurements.

Figure 3 shows a plot of the mean mass loading for all of the days on which data were taken. These values were obtained by averaging the filter data in each 2-hour time interval over the total number of days. This plot reflects the general trend of particulate concentrations showing low values during the night-time hours and relatively high values due to increased activities during the day. All diurnal effects, meteorological effects, and individual excursions are averaged in this curve. The high excursions in the morning, around 9:00 a.m., are believed to be caused partly by a fumigation process which we observed in Norfolk during the summer of 1973 (Ref. 1).

High-Volume Filter Data. The high-volume sampler is the most widely used instrument for measuring the mass concentration of the total suspended particulates. Since Environmental Protection Agency (EPA) standards are based on high-volume sampler measurements, daily high-volume measurements were made over 24-hour periods to relate the concentrations at this location to the national standards.

Particles were collected for 24-hour periods (noon to noon) daily on 8- by 10-inch Watman filter paper in a high-volume sampler on top of the mobile laboratory. The mass concentrations were calculated from the mass of the material collected and the volume of air sampled during each 24-hour period. The weighing procedure is described in Reference 1. The daily mass loadings are listed in Table 2.

TABLE 2
HIGH-VOLUME FILTER DATA

Date	Mass loading
7/26/74	41.3
7/27/74	17.1
7/28/74	19.2
7/29/74	32.7
7/30/74	49.0
7/31/74	68.7
8/1/74	43.8
8/3/74	36.6
8/4/74	50.3
8/6/74	29.6
8/21/74	42.2
8/22/74	33.4
8/23/74	31.5
8/24/74	34.9
8/25/74	29.0
8/26/74	27.2
8/27/74	28.3

The daily mean mass concentration obtained by averaging the Nuclepore filter data over 24-hour periods differ substantially in some cases from the daily mean obtained from the high-volume filter measurements. This is illustrated in Figure 4 where the concentrations measured by the two methods are plotted as a function of day covering a time period from July 26 through August 6, 1974. The two sets of data follow the same general trend showing the con-

centration to be relatively low on the weekends and building up to a peak in the middle of the week. This is roughly consistent with the amount of daily aircraft activity but the Nuclepore filter measurements generally show higher values. These differences between the two data sets are likely due to several factors; the collection efficiency of the high-volume filter decreases with sampling time over long time periods because of the heavy particle buildup. Thus, some of the particles are lost. In addition, some of the filter material is often lost in handling. In both cases, the measured concentration would be lower than the actual concentration. Since each of the Nuclepore filters sampled for only 2 hours, there is usually not enough particle buildup to cause a reduction in collection efficiency. Also, because of the type of material and the size of the Nuclepore filters, there is unlikely to be any tear loss. Thus, it should be expected that the Nuclepore filter measurements would indicate higher mass concentrations.

A 24-hour time period from noon August 20, 1974 through noon August 21, 1974 was selected over which to observe the variation of elemental composition as a function of time. A quarter section of each of the twelve Nuclepore filters which sampled during that period was analyzed by Neutron Activation Analysis (NAA) as described in Reference 1. The masses of a number of elements collected on each filter were determined. Figure 5 shows plots of mass loading as a function of time of day for the six most abundant elements present. The total mass loading (top curve) is also plotted for comparison. The concentration of each element varies with time. Iron constitutes about 10 percent of the total mass loading and there are small traces of vanadium and bromine which constitute about 1 percent of the total. These elements exist in aviation fuel and could possibly be associated with the aircraft operations. It should be noted, however, that roughly these same ratios were observed at the site near downtown Norfolk in 1973 (Ref. 1). The sodium and chlorine are probably from the sea salt.

Elemental analysis over a single 24-hour period does not provide sufficient data to establish any diurnal trends in elemental mass loading. In this particular experiment the cost of analysis was a consideration. It is, however, suggested that the above kind of analysis over several 24-hour periods can yield useful information.

Andersen Data. An 8-stage Andersen cascade impactor was used to measure the mass loading as a function of particle aerodynamic diameter. The sampler separates the particles into 8 size intervals ranging from 0.43 micrometer diameter to 11.0 micrometer diameter (50 percent impaction efficiency points). Air is pulled through the sampler at a constant flow rate. The particles are collected in each stage on a Nuclepore filter substrate (82-mm diameter). Each filter in the cascade was weighed before and after sampling, as for the 47-mm filters, to determine mass of the particles collected, it was necessary to sample for 24-hour periods (noon to noon) on one set of filters to collect enough particles in each stage to register a weight. Therefore, the data obtained represents the size distribution (mass loading vs. particle diameter) averaged over 24 hours. Figure 6 shows normalized size distribution plots for 24-hour periods ending at noon on August 21, 25, and 26. There is a suggestion of a bimodal distribution with one peak occurring at less than 0.43 micrometer and a second one between 1.0 and 10 micrometer. A similar bimodal distribution has been observed by others on the urban aerosols (Ref. 2).

The eight filters that were in the Andersen sampler during the period from noon on August 20 through noon August 21 were each cut into four sections. One section from each impaction stage was analyzed by NAA and a different section from each stage was analyzed by proton-induced X-ray flourescence (Ref. 2). Quantities of Zn, V, Br, and Sn which varied with stage number were identified in each impactor stage. The mass concentration as a function of size as determined by both methods of analysis are plotted in Figure 7. There are quantitative differences in the results from the two methods because of different measuring sensitivities, however, the trends in size distributions are similar. The trends indicate that V, Br, and Sn are concentrated in the small size range (<5-micrometer diameter) and are, therefore, likely to be taken into the human respiratory system. These elements were also identified on the 47-mm Nuclepore filters by NAA which sampled during the same time period. As mentioned above, the presence of these elements may be related to the aircraft activities since they are present in aircraft fuel.

CONCLUSIONS

An experiment in which atmospheric aerosols in a region of high aircraft activities has been described. Data have been presented on the average daily mass loading, mass loading variations with time of day, aerosol size distribution and elemental composition. The mass loadings vary widely with time of day but the average daily loadings are within the EPA standards for clean air. The mean aerodynamic aerosol size data determined by the Andersen cascade impactor suggest a bimodal distribution with one peak in the submicron range and the second peak falling between 1 and 10 micrometers in diameter. Elemental analyses reveal that several of the elements found in aircraft fuel are present in the atmosphere and tend to be attached predominately to the particles in the smaller aerodynamic size range.

The data obtained from these measurements will provide the SAPCB with a partial data base for this location. There is at least a weak suggestion that the aircraft exhaust contributes to the aerosol character. The authors believe that a better assessment of the impact of aircraft operations can be obtained if in situ measurements are made in the direct exhaust of the aircraft in addition to the measurements described in this report.

REFERENCES

1. Storey, R. W., Jr., Sentell, R. J., Woods, D. C., Smith, J. R., and Harris, F. S., Jr.,: "Atmospheric Particulate Measurements in Norfolk, Virginia," NASA TM X-3285, Dec. 1975.

2. Jolly, R. K., Gupta, S. K., Randers-Pehrson, G., Buckle, D. C., Thornton, W. B., Aceto, H., Jr., Singh, J. J., and Woods, D. C.: "Preferential Concentration of Certain Elements in Smaller Aerosols Emitted from Aircraft Engines," J. Appl. Phy., Vol. 46, No. 10, Oct. 1975.

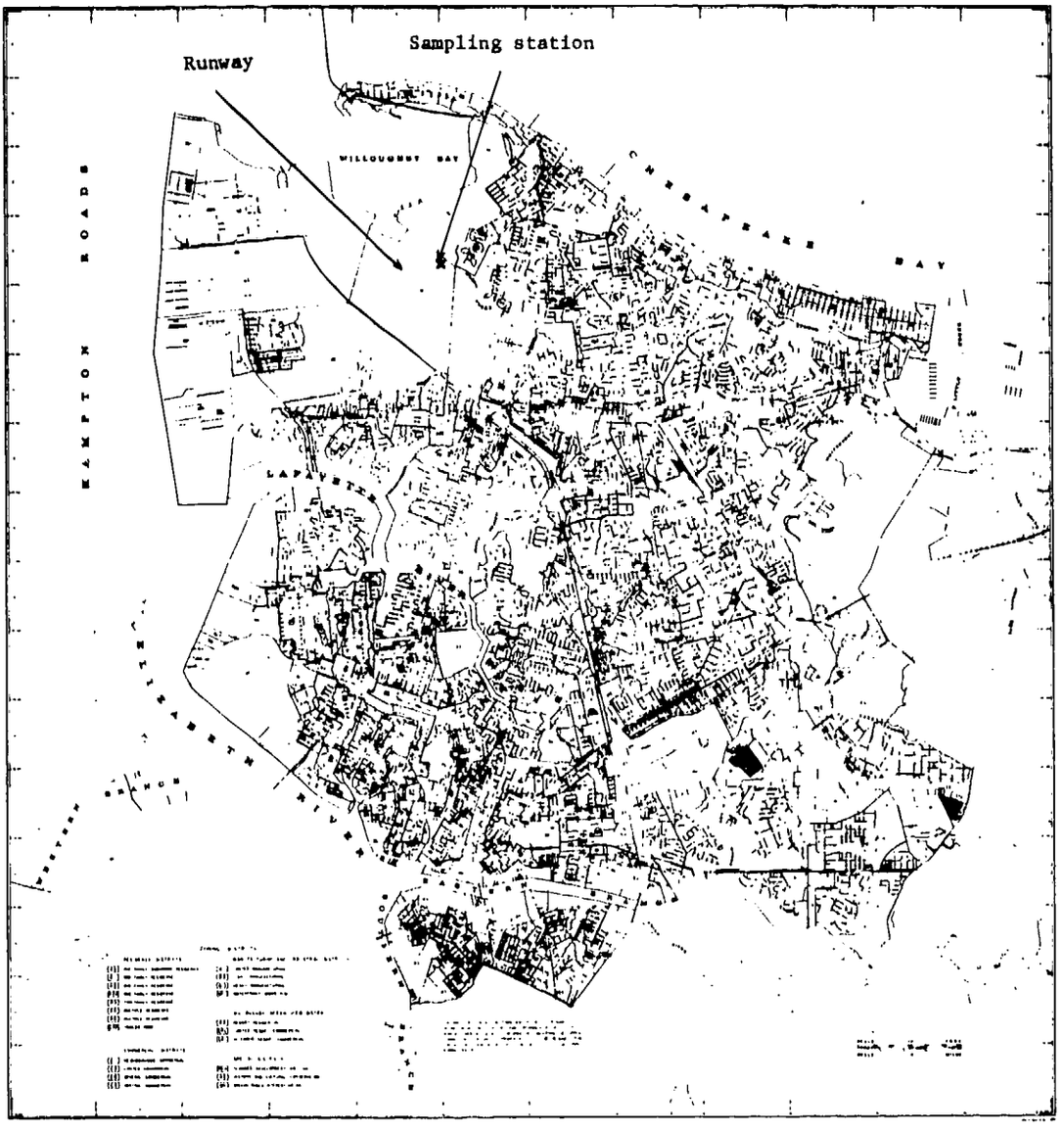


Figure 1.- Map of Norfolk area showing location of sampling station at NAS.

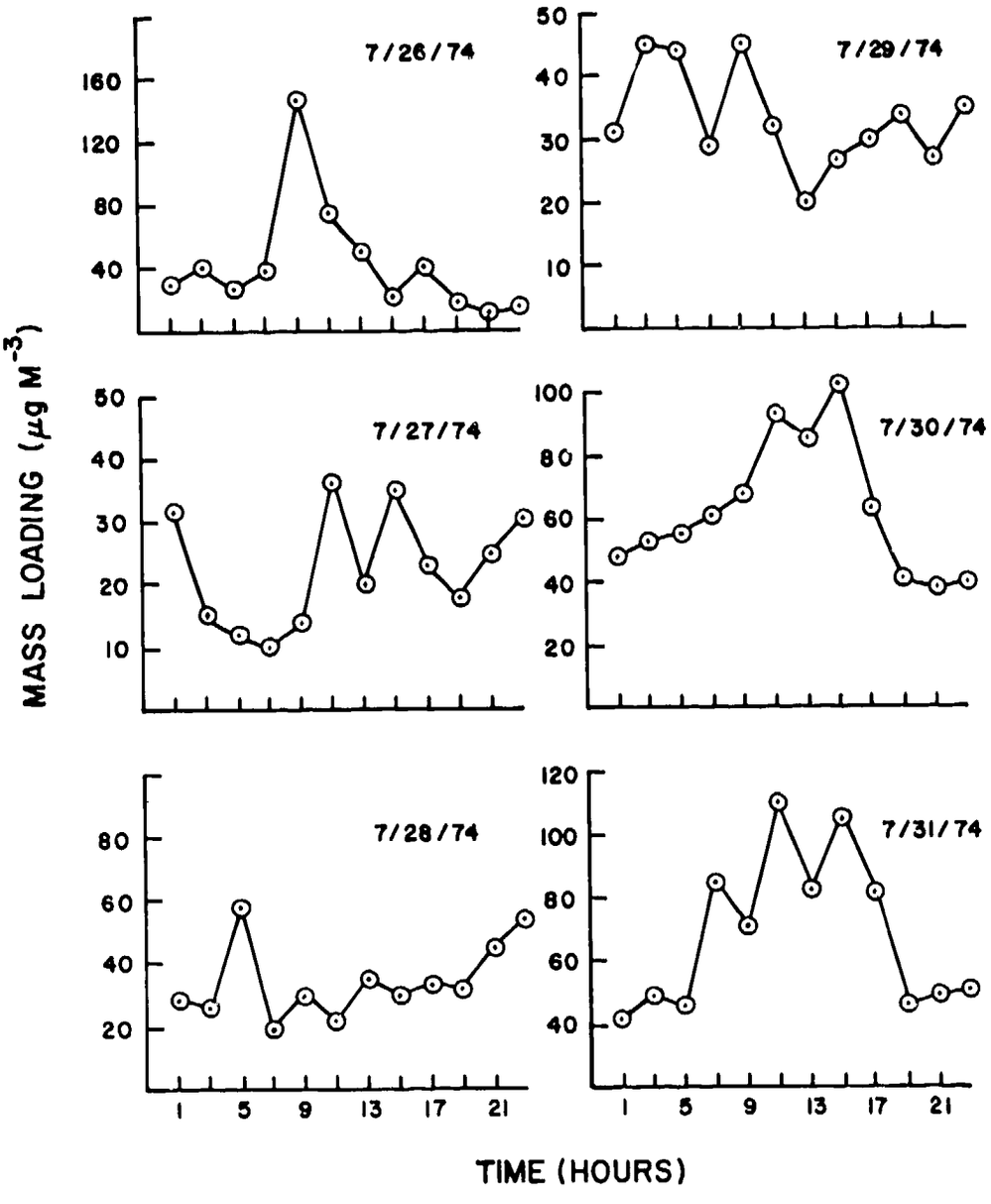


FIGURE 2A.- AEROSOL MASS LOADING AS A FUNCTION OF TIME OF DAY DETERMINED FROM NUCLEPORE FILTER MEASUREMENTS.

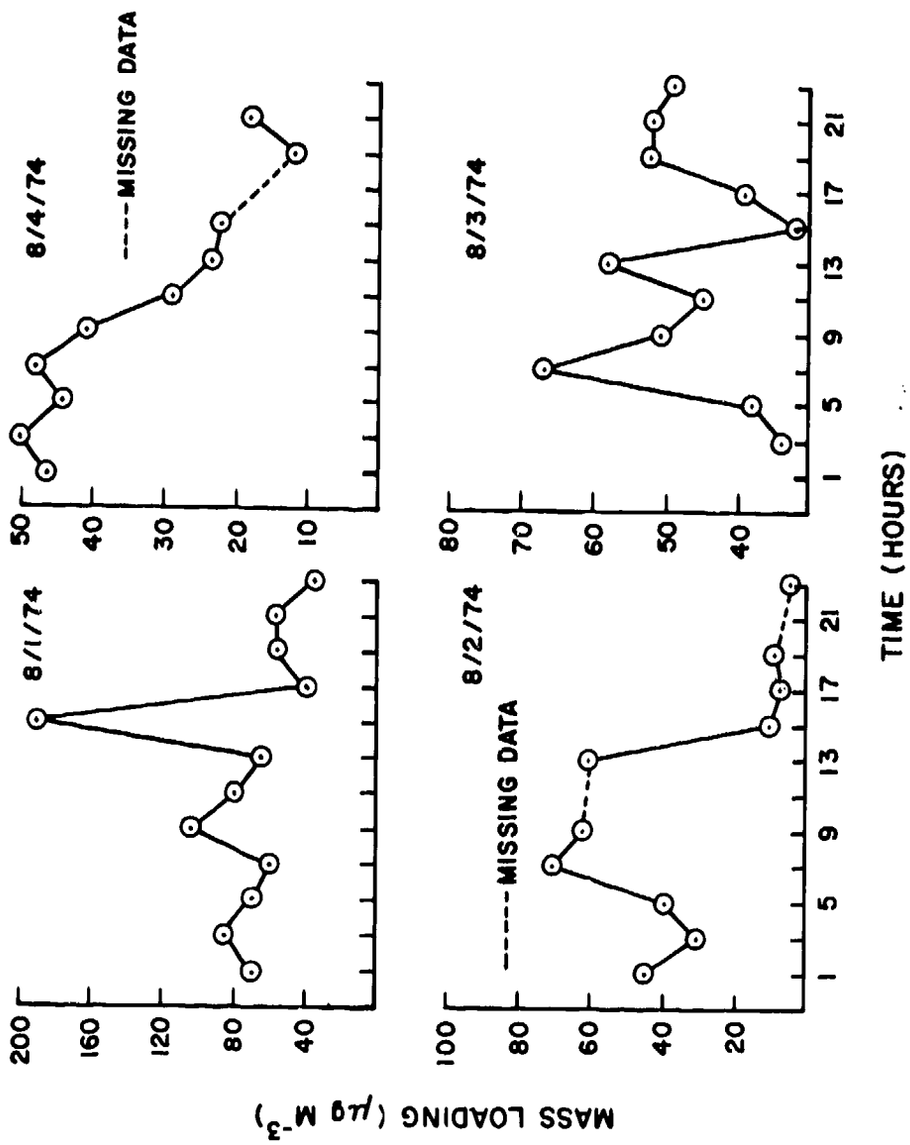


Figure 2b.- Aerosol mass loading as a function of time of day determined from Nuclepore filter measurements.

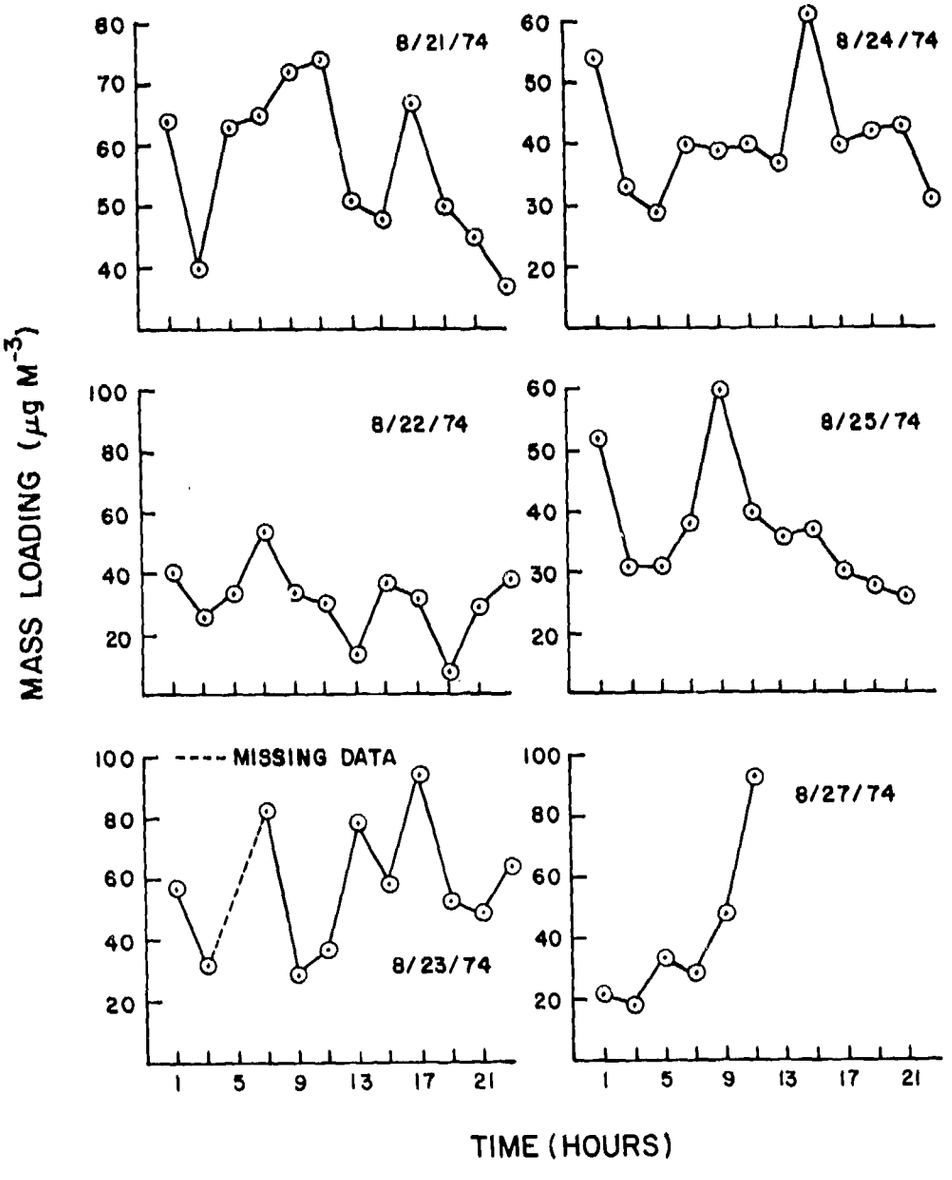


FIGURE 2c.- AEROSOL MASS LOADING AS A FUNCTION OF TIME OF DAY DETERMINED FROM NUCLEPORE FILTER MEASUREMENTS.

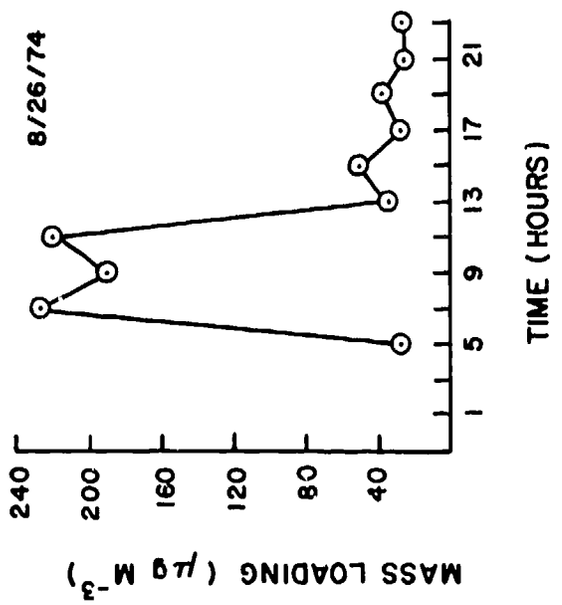


Figure 2d.- Aerosol mass loading as a function of time of day determined from Nuclepore filter measurements.

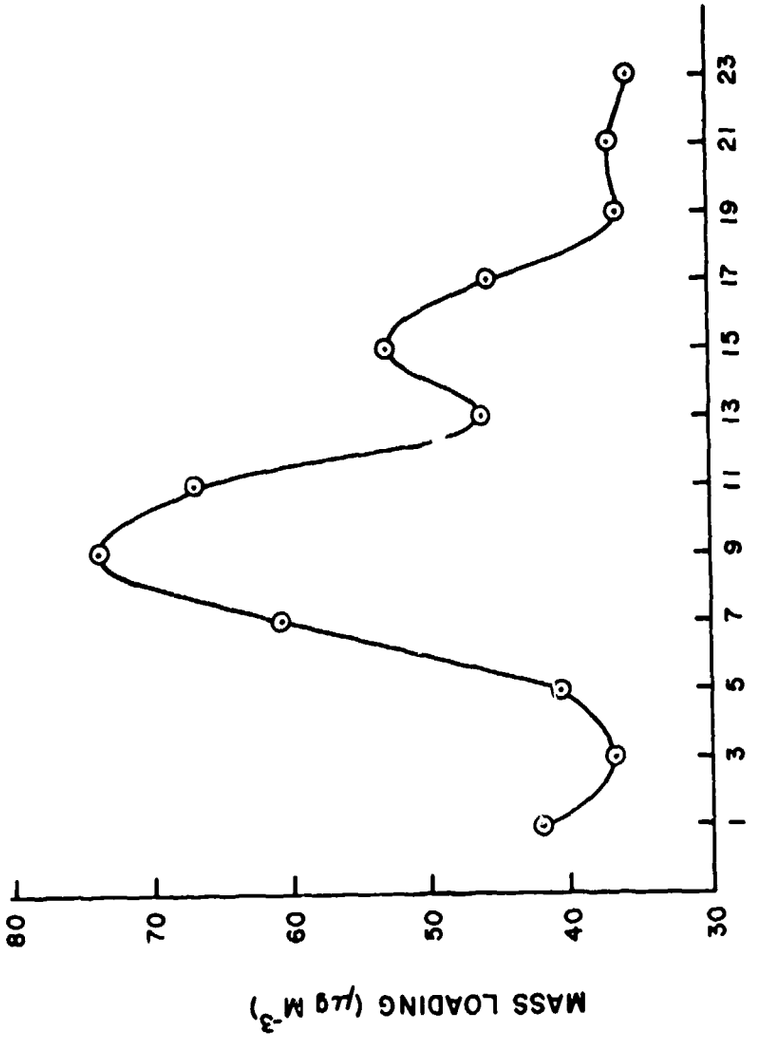


Figure 3.- Mean mass loading as a function of time of day from Nuclepore filter data averaged over all sampling days.

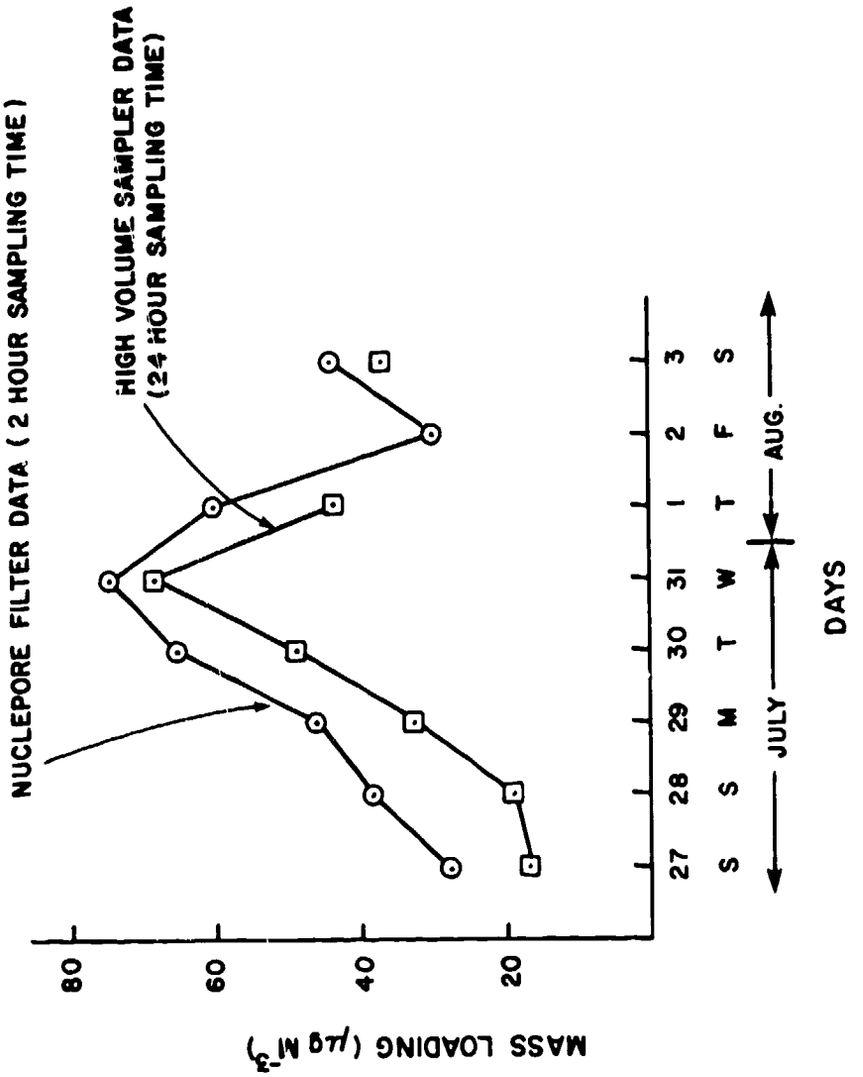


Figure 4.- Daily mean mass loading determined from Nuclepore filters data compared with the daily mass loading determined from the high-volume sampler.

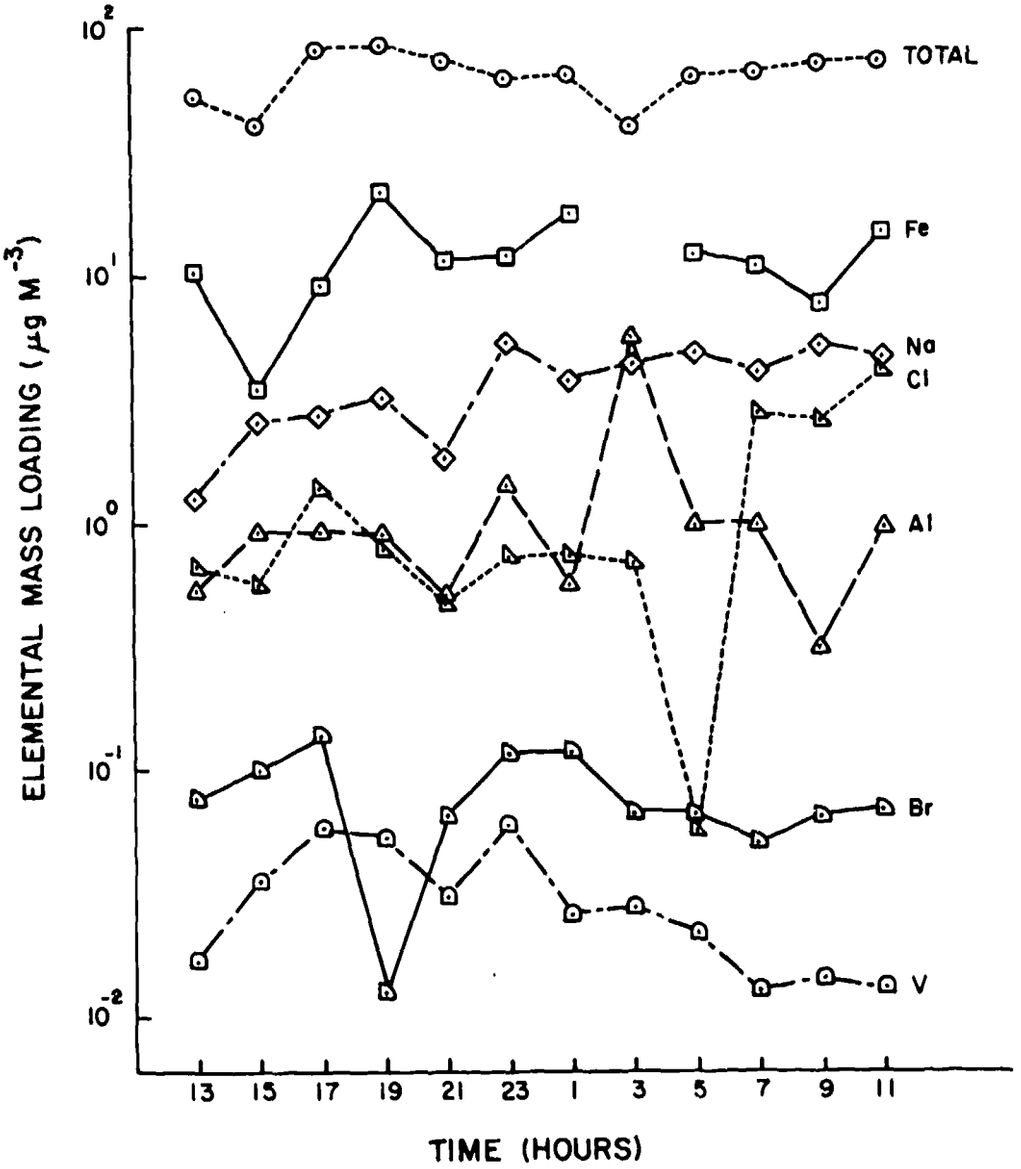


FIGURE 5.- ELEMENTAL MASS LOADING AS A FUNCTION OF TIME OF DAY DETERMINED BY NEUTRON ACTIVATION ANALYSIS.

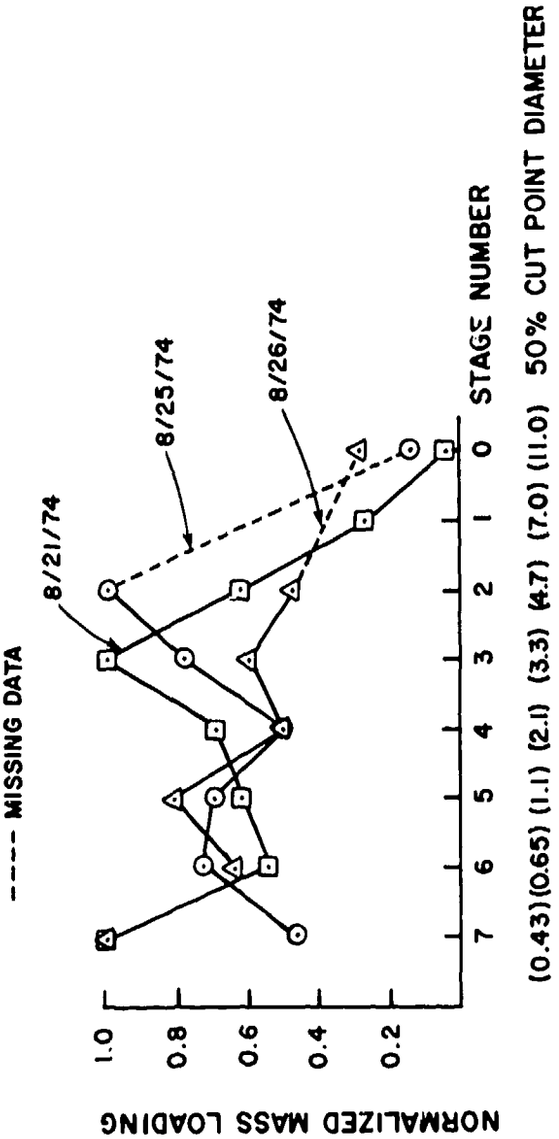


Figure 6.- Normalized size distribution (aerodynamic size) plots for 24-hour periods on August 21, 25, and 26 determined from the 8-stage Andersen impactor.

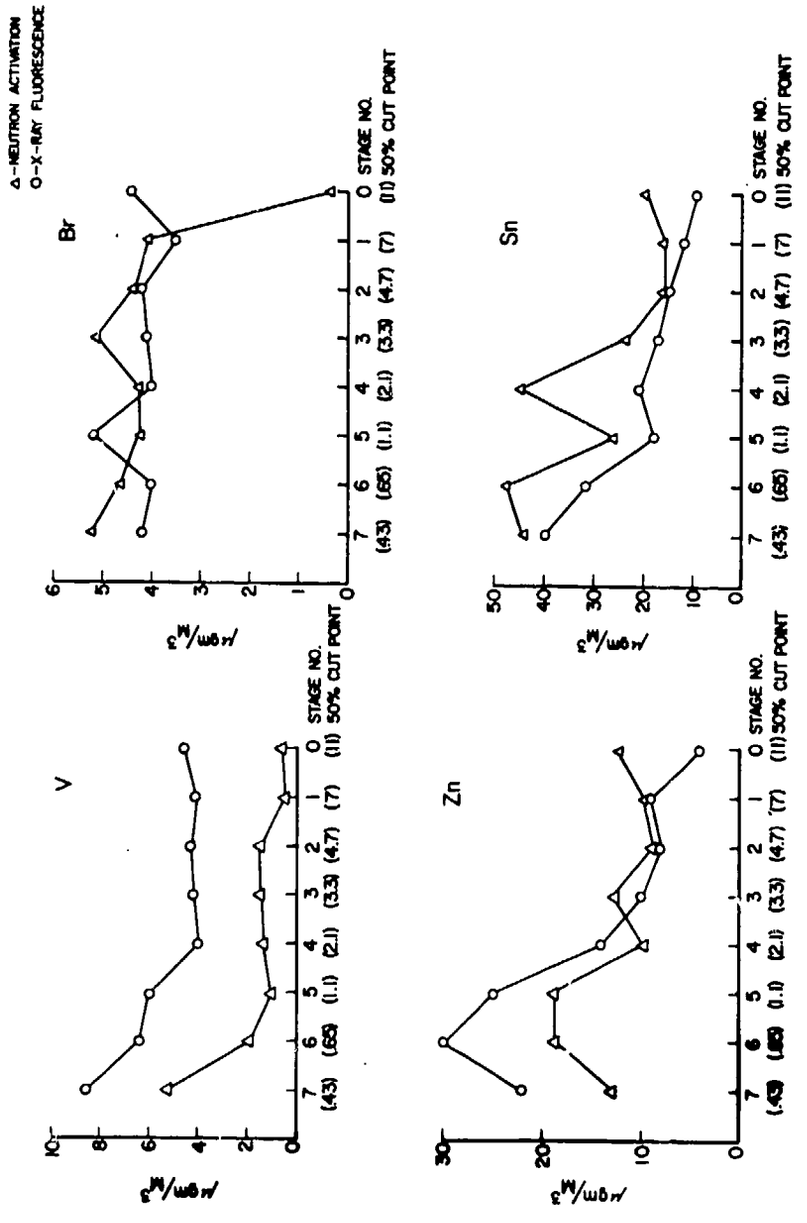


Figure 7.- The mass concentration as a function of aerodynamic size for vanadium, zinc, bromine, and tin collected with an 8-stage Andersen impactor on August 21, 1974, and measured by neutron activation analysis and proton induced x-ray fluorescence.

DISCUSSION

LINDENHOFEN: Two questions: First, to what do you attribute the aluminum in your elemental analysis?

CRUMBLY: I really couldn't find the source for it. The only thing I could attribute it to is some repair work going on at the air station with aircraft: frame and fuselage parts and so forth.

We thought maybe it came from some shop that we were not aware of. This base is over on the Norfolk side of our laboratory, which is located in Hampton, and we are not familiar with any light industrial activity that might be going on around us where we are located.

LINDENHOFEN: The second question: Were you able to correlate your short-term?

CRUMBLY: The purpose of the study was to try to show the State Air Pollution Control Board some techniques they might use other than the crystal ball to pinpoint possible pollution sources.

DALEY: I would like to address Harry's question first. I find the results in great conflict with any modeling studies that have ever been done. As a matter of fact, you are off by at least two orders of magnitude. I can't resolve that in my own mind.

CRUMBLY: You mean in terms of size and distribution?

DALEY: In terms of particulate concentration. We have done extensive modeling studies, including the installation which you have got here, and the highest concentrations we found were on the order of one microgram per cubic meter particulate contribution from aircraft operations and you are reporting concentrations in the order of 100 or 200.

CRUMBLY: No. Let's get something clear. In the first place, we were not able to separate out the concentration that came just from the aircraft. We were not doing this study which the gentleman reported on this morning where he was located right in the exhaust nozzle of the aircraft.

DALEY: The aircraft sources seem implicated, and there seems a disagreement with the modeling studies.

CRUMBLY: Well, I will qualify that again with the statement that we were not able to separate, and I do not know of any technique to separate out, the contribution from just the aircraft.

We were about 300 feet from the runway, which means that we could not sample a particular given manifold of, say, 200 feet by 200 feet.

Whatever we were getting was transported through the area that we were sampling in. And as you know, transport theory is in a stage of flux right now in the area of carrying pollutants from one point to another.

DALEY: From that standpoint, I think the data needs more analysis. Secondly, on your size distribution data, combustion aerosols are normally of the order that we saw this morning, 0.07 microns, and that number is in agreement with several other measurements that have been made, and almost all of your mass came in size increments far above that. That seems to support the thesis that possibly what you were measuring came from somewhere other than aircraft.

I was wondering, for example, if you measured silicon, which is the primary component of dirt, which might be dirt pulled up by aircraft. That could explain the aluminum.

CRUMBLY: If you are familiar with the technique of Neutron Activation Analysis, you know that it is very difficult to separate out aluminum versus silicon. They follow very close to one another. The Neutron Activation Analysis was done for us by BBI in Virginia, so I can't speak for the accuracy of their data; I just report on what we observed.

One would have to look at the whole realm of Neutron Activation Analysis to determine the accuracies of the data.

DALEY: You should be able to get that with Neutron Activation.

CRUMBLY: No. It did not pop up in the data as being high on the list. In other words, the first element that popped up was iron. It was obviously very high. It has always been very high in everything we have done.

Vanadium, bromine, and tin are some of the others that popped up. We went through the literature and began to look at that.

It seems that vanadium and bromine, especially, show up a lot in analysis from internal combustion engines. Dr. Harris has put out a paper on that. As a matter of fact, he may have it. I am not sure. It is a NASA Contractor Report. I am looking at elemental analysis from various sources.

DALEY: I think the big point to be made is that there are a lot of questions to be answered. There are far too many disagreements.

CRUMBLY: I appreciate your comments, but I hope I didn't preface the paper with the remark that these were strictly from aircraft. I tried to preface the remarks that it was taken on an air base and we were about 300 feet from the end of the runway.

ROTE: Just to pursue Pete Daley's comments a little bit further, one of the techniques that has been used, for example, by Jack Winchester and some of his colleagues in an aerosol analysis is to essentially normalize the elemental concentrations by crustal abundance.

Essentially, you look at the ratio of crustal material present in the earth's crust and normalize all of your concentrations to that. Then you look at enrichment factors. This is a much more general way of getting at the influence of material being brought up from the ground.

Winchester and others have also done this both over continental areas and over ocean areas, and there is very often a very considerable difference between air coming off the ocean and air coming off land masses.

I suggest you might pursue this approach as one way to get a better idea of where your material is coming from.

The other method of general analysis is due to Friedlander and some of his colleagues. He looks for fingerprints of materials by a matrix conversion technique. It can give you a rough idea of what kinds of sources are contributing to concentrations. I gather Harris has done something along these lines.

CRUMBLY: That is why the vanadium and bromine popped up. When you look at the literature, there is some literature to say those elements are heavily involved in internal combustion engines.

ROTE: I guess the only problem I would have is this: Is there any way you can distinguish between aircraft fuels and automotive fuels?

CRUMBLY: We are not aware of any tracer element at this time. At least I am not aware of it, and no one in my group is aware of any tracer we could have used or we would have tried it. We would have tried to pull out the contribution from aircraft versus contribution of other sources. If anyone is aware of a tracer, I would be glad to know about it.

ROTE: Benzene is soluble. Have looked at that?

PRELIMINARY EVALUATION OF AIR QUALITY ASSESSMENT MODEL AT WILLIAMS AIR FORCE BASE

D. M. Rote, R. J. Yamartino, and K. L. Brubaker

Argonne National Laboratory
Energy and Environmental Systems Division

ABSTRACT

A preliminary evaluation of the accuracy of Argonne's Air Quality Assessment Model (AQAM), using data collected for this purpose at Williams Air Force Base (WAFB), is described here. AQAM, an atmospheric dispersion model, simulates the local air quality impacts of military aircraft operations. Air quality, meteorological, and emissions data were collected at WAFB. While measured pollutant concentrations were quite low, model testing is possible; and, for carbon monoxide, a significant correlation exists between hourly aircraft emissions and observed hourly air quality. The prime meteorological requirement--that the local windfield be spatially homogeneous--seems to be satisfied most of the time. AQAM-predicted pollutant concentrations are in the same range as observed levels, and about 50% of the predictions are within a factor of two of the corresponding observations. Theory and experiment essentially agree on the pollutant rank ordering of the WAFB air quality monitoring stations. Future work will include more detailed model testing.

ARGONNE NATIONAL LABORATORY (ANL) was contracted several years ago by the U.S. Air Force Weapons Laboratory to develop the Air Quality Assessment Model (AQAM).(1)* The model is designed for use by Air Force personnel in assessing the air quality impacts of air base operations on surrounding communities. The present model, which is similar in terms of its treatment of atmospheric dispersion to the Argonne Airport Vicinity Air Pollution (AVAP) model developed for use at commercial airports (2), incorporates a detailed simulation of pollutant source terms that are specific to air bases. Particular attention is given to military aircraft operations and their pollutant emission rates.

Unfortunately, until now, a data base suitable for determining the limits of accuracy of the AQAM has not been available. Some data bases have been developed for use in evaluating commercial airport models, including those described in Refs. 3-12, but those were considered for a number of reasons to be unsuitable for Air Force purposes. Reviews of monitoring efforts at commercial airports and model validation exercises are given in Refs. 13 and 14.

Consequently, a large data acquisition program was undertaken by the Air Force at Williams Air Force Base (WAFB) in Phoenix, Arizona. Using funds supplied by the Air Force and Navy, the U.S. Environmental Protection Agency (EPA) Environmental Monitoring and Support laboratory at Las Vegas performed the measurement portions of the program. Stanford Research International prepared a detailed emission inventory of air base and surrounding environ pollutant sources. The EPA and a subcontractor, Northrop Corporation, recently compiled the measurement and air quality data and ANL now is analyzing the data and defining the limits of accuracy of the AQAM. Preliminary draft reports have been prepared by ANL (15) and the EPA and Northrop (16).

In addition to analyzing the data and evaluating the model, ANL is preparing a documented, user-oriented data set that will be available to interested groups. The various data acquisition and manipulation steps involved in producing the test data set are illustrated in Fig. 1.

This paper, which summarizes the results of the data analysis and model tests performed to date, is based largely on work completed within the last several months. It briefly describes the "hypothesis testing approach" used in the program and summarizes the results of the analysis of the air quality, meteorological, and emission data. A synopsis of the model testing work and some preliminary results are presented, as are conclusions and plans for future work.

HYPOTHESIS TESTING APPROACH

The main approach used in the data analysis and model testing program is the apriori development of assumptions, hypotheses, and questions regarding the data and the model. Examples of assumptions regarding the data are:

1. All instrumentation and data acquisition systems function properly and reliably.
2. The sampling rates for meteorology and pollutants are sufficiently high. (This assumption was subsequently checked by a high sampling rate experiment.)
3. The data sample is sufficiently large and covers a wide enough range of meteorological and source activity conditions to test the hypotheses stated below.
4. The reproducibility and repeatability errors associated with the sampling system are known or will be determined. (Reproducibility refers to observed differences

*Numbers in parentheses designate references at end of paper

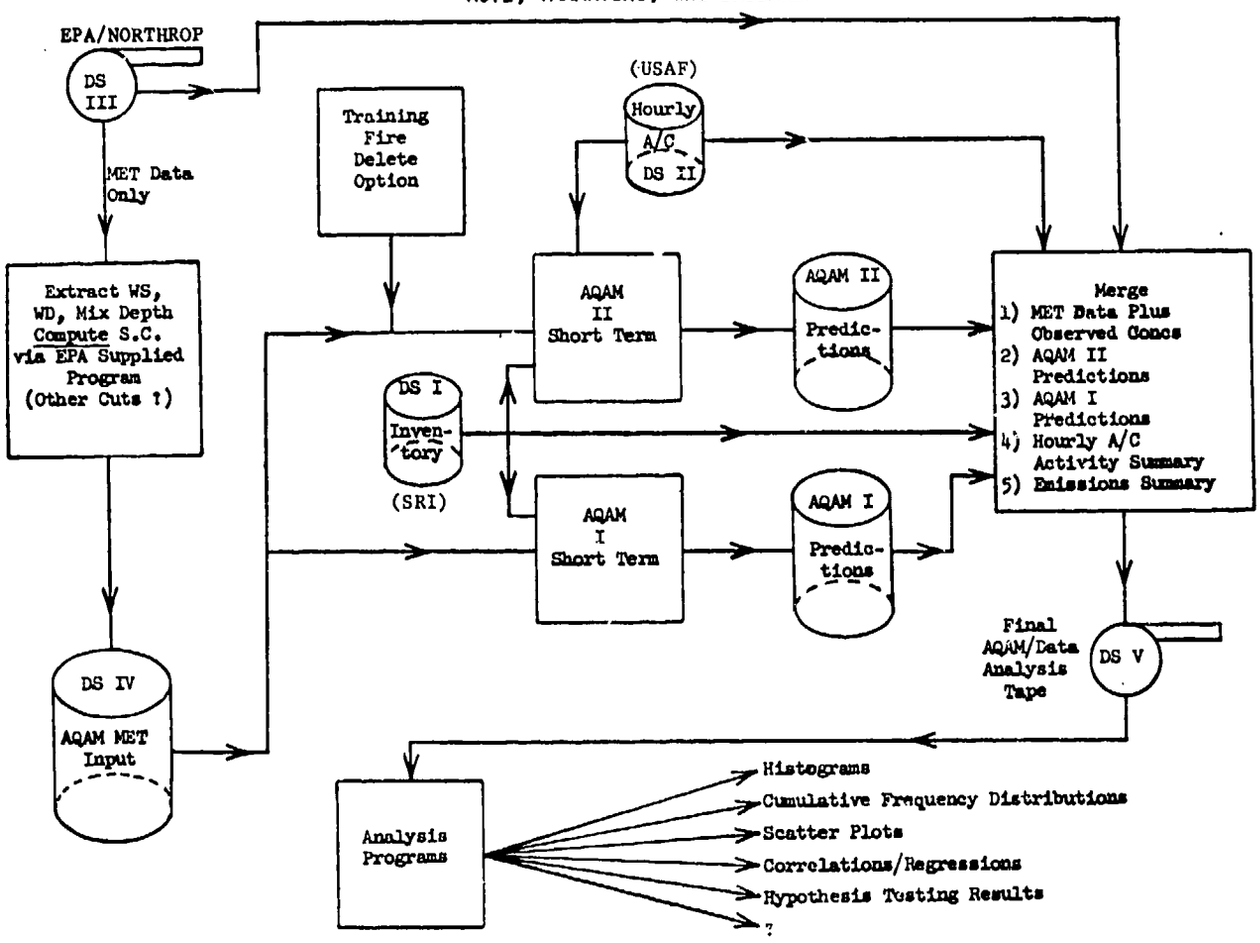


Fig. 1 – Air Quality Assessment Model analysis data flow

between similar instruments measuring the same quantity while repeatability refers to the differences observed when a single instrument measures the same quantity many times.)

In contrast to these assumptions, which merely state what is assumed to be true about the data, are statements (i.e., hypotheses) that can be tested or verified by properly designed analyses of the data, model predictions, etc. The testing of the hypotheses forms the basis of conclusions regarding such issues as the suitability of the data set for model evaluation purposes and the limits of accuracy of the model. Examples of hypotheses that address the suitability of the data set for model evaluation purposes are:

1. *The hour-to-hour variations in signal strength are significant with respect to system repeatability noise for all instruments.* This hypothesis can be tested by direct comparison of mean signal strength to instrument threshold and the standard deviation of hourly fluctuations about the mean to repeatability noise as determined by the EPA or instrument manufacturer.
2. *The station-to-station variations in signal strength are significant with respect to reproducibility errors a reasonable fraction of the time* (so as to provide adequate statistics). This can be tested by comparing the root-mean-square residual between hourly average concentrations at a single station and the all-station hourly mean to the instrument reproducibility errors as determined by the EPA or instrument manufacturer.
3. *The aerometric signals are correlated with the aircraft operations activity information.* Simple scatter diagrams of level of aircraft activity versus average pollution concentration and peak concentration are suggested for the preliminary analysis.

Finally, questions can be formulated regarding the data and model predictions that require answers in order to complete the analysis but whose answers, by themselves, do not address the more pertinent issues of the program. Examples of such questions are:

1. Is plume rise from aircraft a significant factor when the monitoring station is close to a taxiway/runway?

2. Under what meteorological conditions will the selected monitoring sites provide adequate data on background levels?
3. Which weather station provides wind speed and direction data most representative of conditions throughout the air base?

Formulating these types of assumptions, hypotheses, and questions, and then answering the questions and testing the hypotheses, constitutes the "hypothesis testing approach." Examples of some of the questions and hypotheses that have been addressed so far are given in the remainder of this paper.

DATA ANALYSIS

THE DATA SET - The data set compiled at Williams Air Force Base consists of 13 months of air quality and meteorological data collected at the five stations shown on Fig. 2, meteorological data routinely recorded at the base weather station, hourly aircraft activity data (counts of aircraft using each runway by aircraft type, compiled by base staff), and an emission inventory listing air base and environ stationary and mobile sources. The measured aerometric and meteorological quantities are listed in Table 1. Although many analyses of the data have been performed during the past several months, only a few illustrative examples are reported here.

AIR QUALITY DATA - Before presenting a statistical summary of the aerometric data, we will first define the range of data values regarded as acceptable or physically allowable (given the instrument range setting, instrument threshold and accuracy), as well as the "data windows" used in the computer program that generates the hourly average data tape. Some discussion of the selection of "data windows" is given in Ref. 16; however, our selection of threshold concentrations C_T (such that concentrations, C, in the range $C_{MIN} < C < C_T$ are set equal to C_T) is based on a combination of conversations with the experimenters, instrument manufacturer's specifications, and a strong desire to avoid taking the logarithm (in order to compute geometric means) of a number too close to zero. The measured and computed minimum, maximum, and threshold concentrations for eight pollutants are given in Table 2.

As a first step before more detailed analyses, it is often instructive to examine the frequency distributions of the measured quantities; examples are shown in Figs. 3 and 4. Visual inspection of such distributions quickly gives one an estimate of the mean, median, standard deviation, range, and statistical nature (e.g., normal, log-normal) of the measurables and occasionally reveals systematic problems in the data. For example, an uncharacteristic bimodal shape in the Station 2, October carbon monoxide distribution led to the discovery of an instrument calibration problem that had existed during a two-week period.

Statistical properties of the entire 13-month data sample are given in Table 3. Similar summaries exist for each month, but are not included here.

Referring back to the hypothesis on signal-to-noise ratio (Hypothesis #1 on previous page), we see that a reasonable fraction of the data lies well above instrument threshold and noise levels for all stations. Further insight into the hour-to-hour variations can be obtained from typical three-dimensional concentration time histories (see Fig. 5) and diurnal variations of mean concentrations (see Fig.6).

A somewhat better way to view the statistical nature of the measured quantities is to display cumulative frequency distributions. Examples of cumulative frequency distributions for the 13-month data sample are presented in Fig. 7 in log-probability form. The interesting characteristic of the log-probability plot is that a log-normal distribution transforms into a straight line that intercepts the 50-percentile point at the geometric mean and has a slope proportional to the geometric standard deviation. Table 4 summarizes some properties of the cumulative frequency distributions for each pollutant and for each monitoring station. In all cases, the value given for the 99.99 percentile is the second highest value. (The highest value is excluded since using it would require the

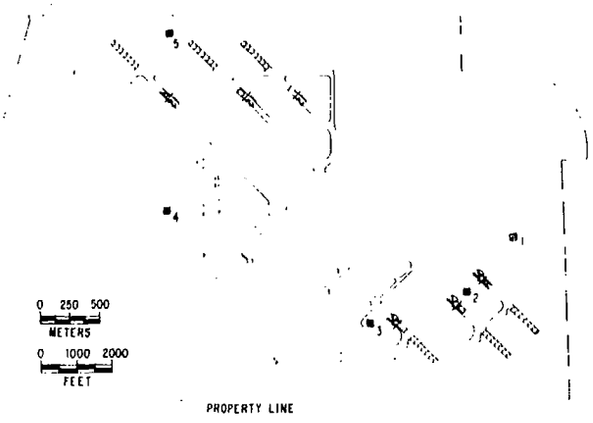


Fig. 2 - Diagram of Williams Air Force Base, showing the five air quality monitoring stations as solid squares.

Table 1 - Variables Measured at Williams Air Force Base

Aerometric Variables

- At five stations: CO, NO_x, NO_2, THC, NMHC, b_{SCAT}

Meteorological Variables

- At five stations: wind speed and direction, σ_θ
- At base weather station: all standard WABAN meteorological variables
- Other measurements: depth of mixing layer (acoustic sounder), solar insolation, atmospheric turbulence (u, v, w) vertical temperature gradient.

Table 2 - Minimum, Maximum, and Threshold Concentration Values

Pollutant	Concentrations (in ppm unless otherwise indicated) Minimum (C_{MIN})	Maximum (C_{MAX})	Threshold (C_T)
Nitric Oxide (NO)	-0.02	0.5	0.002
Oxides of Nitrogen (NO_x)	-0.02	0.5	0.002
Methane (CH_4)	1.25	8.0	1.3
Total Hydrocarbon (THC)	1.25	8.0	1.3
Carbon Monoxide (CO)	0.0	8.0	0.05
Nephelometer Readings (b_{SCAT})	0.0	9.9[a]	0.1[a]
Nitrogen Dioxide [NO_2 (= NO_x - NO)][b]	-0.2	0.5	0.002
Nonmethane Hydrocarbons [NMHC (= THC - CH_4)][c]	-0.2	8.0	0.05

[a] Values given in units of 10^{-4} m^{-1}.

[b] Including C_{MIN} and C_{MAX} bounds on NO_x and NO.

[c] Including C_{MIN} and C_{MAX} bounds on THC and CH_4.

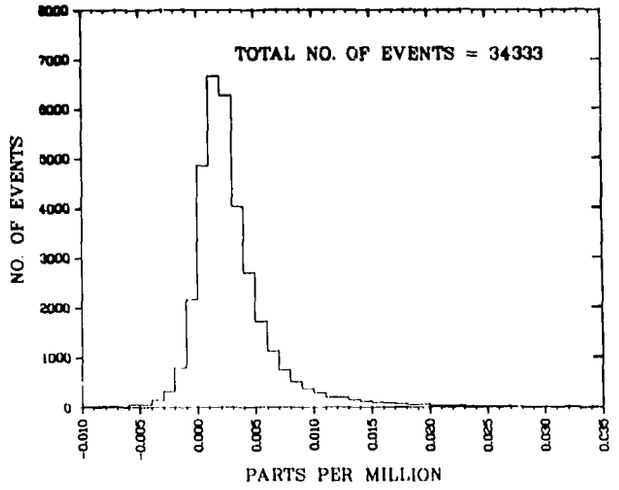


Fig. 3 - Frequency distribution for hourly average nitric oxide levels at WAFB, June 1976 - June 1977, all stations

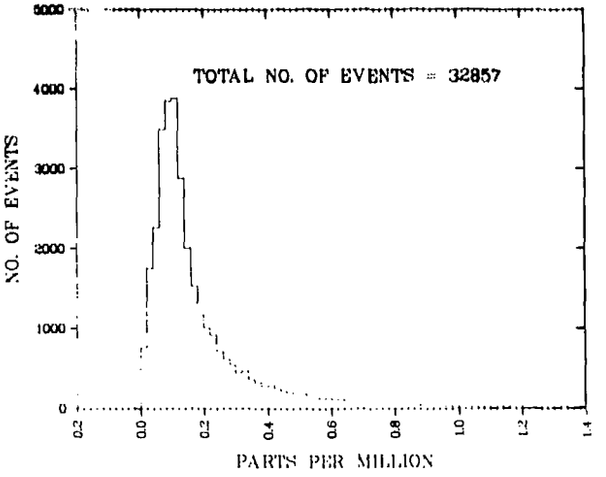


Fig. 4 - Frequency distribution for hourly average carbon monoxide levels at WAFB, June 1976 - June 1977, all stations

presentation of 100% of the data which is not possible in such a graph.) It can be seen from Table 4 that, with the exception of Station 4, the stations observe rather similar cumulative frequency distributions for the various pollutants. An examination of the source environments of each monitoring station indicates that whereas Stations 1, 2, 3, and 5 are exposed to aircraft-related effluents during idling, taxiing, and runway operations, Station 4 is more isolated from aircraft sources (except during easterly winds) and tends to be much more influenced by surrounding stationary and mobile sources (internal combustion and diesel engines). This station placement was, of course, by design. Although not discernible from the data given, the cumulative frequency distributions tend to indicate that most of the aerometric variables are log-normally distributed. Methane and total hydrocarbons (of which the dominant fraction is methane), depart significantly from log-normality. In fact, methane appears to be more normally than log-normally distributed, as one would expect for a quantity having a global nature (i.e., not resulting from identifiable isolated sources).

Table 3 - Williams Air Force Base Data for the Period June 1, 1976, to June 30, 1977

	NITRIC OXIDE (NO)	NITROGEN DIOXIDE (NO2)	OXIDES OF NITROGEN (NOX)	METHANE (CH4)	TOTAL HYDROCARBON (THC)	NONMETHANE HYDROCARBON (NMHC)	CARBON MONOXIDE (CO)	NEPHELOMETER READING (BSCAT)
STATION NUMBER ... 1								
NO. VALUES	6224	6163	6396	4569	5022	4537	5056	6326
ARITHMETIC MEAN	2.7146E-03	7.5550E-03	1.0262E-02	1.6020E 00	1.6369E 00	6.4091E-02	1.3877E-01	5.5308E-01
STD. ARITH. DEVIATION	4.4181E-03	9.3210E-03	1.1002E-02	1.4195E-01	2.0803E-01	9.8959E-02	1.5311E-01	3.9441E-01
GEOMETRIC MEAN	1.8402E-03	5.1084E-03	7.4278E-03	1.5973E 00	1.6260E 00	4.0122E-02	1.0212E-01	4.5630E-01
STD. GEOM. DEVIATION	2.6016E 00	2.5505E 00	2.2439E 00	1.0849E 00	1.1256E 00	3.1804E 00	2.1086E 00	1.8895E 00
MINIMUM VALUE	-1.0100E-02	-2.0000E-02	-4.5000E-03	1.2500E 00	1.2535E 00	-1.7630E-01	0.0	0.0
MEDIAN VALUE	1.9000E-03	5.3000E-03	7.6000E-03	1.6150E 00	1.6510E 00	4.8500E-02	9.6100E-02	4.6940E-01
MAXIMUM VALUE	1.5150E-01	1.1520E-01	2.6670E-01	3.3387E 00	4.4430E 00	1.5543E 00	2.3814E 00	6.8138E 00
STATION NUMBER ... 2								
NO. VALUES	7424	7377	7435	7025	6335	6071	7175	7484
ARITHMETIC MEAN	2.9369E-03	8.8131E-03	1.1731E-02	1.6228E 00	1.6983E 00	7.6455E-02	1.7096E-01	5.9251E-01
STD. ARITH. DEVIATION	4.1286E-03	9.2010E-03	1.0638E-02	1.1742E-01	2.0967E-01	1.3824E-01	1.6074E-01	4.5753E-01
GEOMETRIC MEAN	2.5318E-03	5.8820E-03	9.0296E-03	1.6208E 00	1.6880E 00	5.4558E-02	1.3266E-01	4.6900E-01
STD. GEOM. DEVIATION	2.0879E 00	2.6540E 00	2.0733E 00	1.0626E 00	1.1206E 00	3.7330E 00	2.0159E 00	2.0351E 00
MINIMUM VALUE	-1.0500E-02	-1.1500E-02	-8.0000E-03	1.2871E 00	1.2797E 00	-2.0000E-01	0.0	0.0
MEDIAN VALUE	2.6000E-03	6.4000E-03	9.0000E-03	1.6030E 00	1.7040E 00	7.9300E-02	1.2450E-01	4.9470E-01
MAXIMUM VALUE	1.6030E-01	1.3120E-01	2.9150E-01	3.1203E 00	4.3471E 00	1.3517E 00	3.8692E 00	7.4879E 00
STATION NUMBER ... 3								
NO. VALUES	7347	7323	7323	7232	7187	7105	7056	7368
ARITHMETIC MEAN	2.5409E-03	1.0189E-02	1.2735E-02	1.5875E 00	1.6687E 00	8.2497E-02	1.2572E-01	6.0618E-01
STD. ARITH. DEVIATION	3.7039E-03	1.0031E-02	1.1947E-02	1.2874E-01	1.8488E-01	1.1369E-01	1.5507E-01	4.8558E-01
GEOMETRIC MEAN	2.0523E-03	7.4157E-03	9.6805E-03	1.5846E 00	1.6620E 00	4.9582E-02	8.7014E-02	5.0570E-01
STD. GEOM. DEVIATION	2.2766E 00	2.2515E 00	2.0963E 00	1.0720E 00	1.0986E 00	3.3767E 00	2.2342E 00	1.8078E 00
MINIMUM VALUE	-6.2000E-03	-1.3200E-02	-9.7000E-03	1.3061E 00	1.3043E 00	-1.8310E-01	0.0	0.0
MEDIAN VALUE	2.0000E-03	7.3000E-03	9.3000E-03	1.5810E 00	1.6370E 00	6.4200E-02	8.0800E-02	5.1300E-01
MAXIMUM VALUE	1.3320E-01	1.1360E-01	2.4120E-01	3.7748E 00	5.1778E 00	3.5704E 00	3.6703E 00	8.5104E 00
STATION NUMBER ... 4								
NO. VALUES	6855	6772	6814	6789	6810	6718	6632	6956
ARITHMETIC MEAN	5.2692E-03	1.4083E-02	1.9159E-02	1.6712E 00	1.8624E 00	1.9062E-01	3.5011E-01	5.7140E-01
STD. ARITH. DEVIATION	8.0001E-03	1.4937E-02	1.9591E-02	1.9712E-01	3.5348E-01	2.3231E-01	3.6401E-01	4.1328E-01
GEOMETRIC MEAN	3.4174E-03	9.2642E-03	1.3134E-02	1.6635E 00	1.8387E 00	1.1200E-01	2.0308E-01	4.6556E-01
STD. GEOM. DEVIATION	2.7528E 00	2.7158E 00	2.5164E 00	1.1032E 00	1.1676E 00	3.5447E 00	3.5700E 00	1.9237E 00
MINIMUM VALUE	-9.2000E-03	-1.8000E-02	-1.7400E-02	1.3151E 00	1.3364E 00	-1.9630E-01	0.0	0.0
MEDIAN VALUE	3.3000E-03	9.9000E-03	1.3800E-02	1.6230E 00	1.7750E 00	1.5120E-01	2.4330E-01	4.7550E-01
MAXIMUM VALUE	1.8080E-01	1.5020E-01	3.2670E-01	4.2962E 00	7.1507E 00	4.9516E 00	3.9774E 00	5.7665E 00
STATION NUMBER ... 5								
NO. VALUES	6532	6516	6692	6860	7003	6819	7042	7248
ARITHMETIC MEAN	3.1779E-03	8.1606E-03	1.1245E-02	1.6570E 00	1.7221E 00	6.4449E-02	1.9881E-01	5.7044E-01
STD. ARITH. DEVIATION	4.0842E-03	1.0380E-02	1.1358E-02	1.4933E-01	2.1940E-01	1.1436E-01	1.9780E-01	4.0103E-01
GEOMETRIC MEAN	2.5755E-03	5.3495E-03	7.8869E-03	1.6533E 00	1.7125E 00	4.4781E-02	1.4994E-01	4.6845E-01
STD. GEOM. DEVIATION	2.3979E 00	2.7691E 00	2.4681E 00	1.0762E 00	1.1136E 00	3.1899E 00	2.0444E 00	1.9049E 00
MINIMUM VALUE	-1.1000E-02	-1.8600E-02	-5.4000E-03	1.3619E 00	1.3088E 00	-1.9830E-01	0.0	0.0
MEDIAN VALUE	2.4000E-03	5.5000E-03	8.2000E-03	1.6240E 00	1.6850E 00	5.8100E-02	1.3310E-01	4.7930E-01
MAXIMUM VALUE	6.4800E-02	1.0320E-01	1.1110E-01	3.5836E 00	6.3742E 00	3.6069E 00	2.1784E 00	4.7254E 00

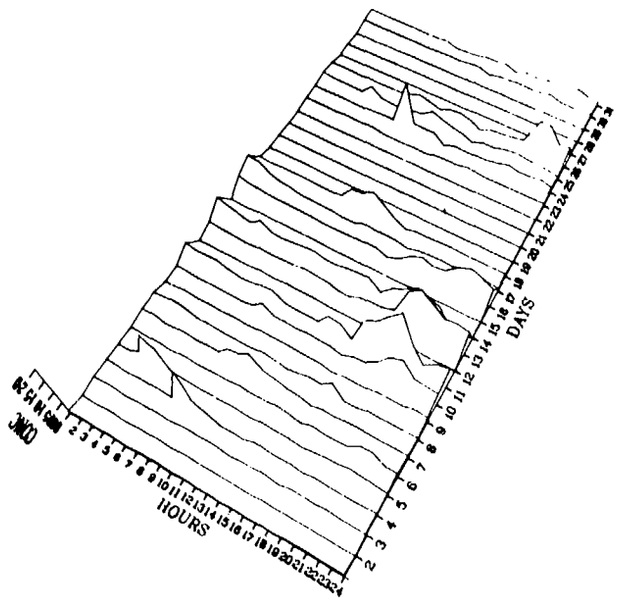


Fig. 5 - Three-dimensional time history of observed carbon monoxide concentrations at Station 2 during January 1977

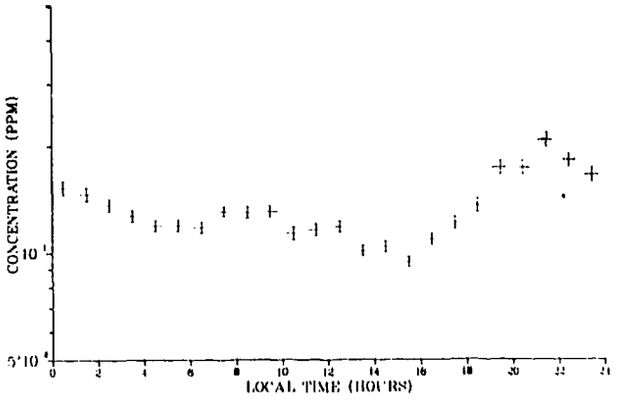


Fig. 6 - Diurnal variations of mean carbon monoxide concentrations at WAFB, Station 2

METEOROLOGICAL DATA - Analysis of the meteorological data reveals several interesting features. First, from the viewpoint of applicability of Gaussian-type plume models (such as AQAM) it is important to examine the degree of homogeneity of meteorological conditions over the entire air base during each one-hour averaging period. For this purpose, it is useful to define two quantities, or "q-factors,"

$$q_u^2 \equiv \frac{1}{n} \sum_{i=1}^{n} \frac{(u_i - \bar{u})^2}{\bar{u}^2}$$

$$q_\theta^2 \equiv \frac{1}{n} \sum_{i=1}^{n} \frac{(\theta_i - \bar{\theta})^2}{\bar{\sigma}_\theta^2}$$

where: u_i and θ_i are the wind speed and direction at the ith station, $\bar{u}$ and $\bar{\theta}$ are their n-station means, and $\bar{\sigma}_\theta$ is the n-station mean standard deviation of wind direction within the hour.

These quantities q_u and q_θ measure, within a given hour, the root-mean-square relative deviation of individual station measurements of wind speed (u_i) and wind direction (θ_i) about their respective n-station means for that hour. The smaller the q_u and q_θ values, the more spatially homogeneous the wind field.

Figure 8 shows a frequency distribution of q_u factors (one for each hour of data) based on deviations of wind speed from the four-station (Station 4 excluded) average wind speed. This figure indicates that for almost all hours the deviations are less than 20%. On the other hand, when a similar plot is made of the deviations of Station 4 wind speed readings from the four-station mean (Station 4 excluded) the deviations are found to be substantially greater, as shown in Fig. 9. Similar results are obtained for the q_θ factors. Hence, not only is Station 4 distinct from the other stations with

Table 4 - Cumulative Frequency Distributions of Air Quality Data from WAFB June 1976 - June 1977

	Monitoring Station Number				
Percentile	1	2	3	4	5
Nitric Oxide					
50	0.002	0.003	0.002	0.003	0.002
95	0.008	0.007	0.007	0.018	0.010
99	0.016	0.016	0.015	0.038	0.016
99.99	0.106	0.115	0.094	0.131	0.059
Std. Dev.*	2.60	2.09	2.05	2.75	2.40
Nitrogen Dioxide					
50	0.005	0.006	0.007	0.010	0.006
95	0.022	0.026	0.028	0.044	0.028
99	0.047	0.045	0.053	0.074	0.051
99.99	0.108	0.113	0.108	0.147	0.097
Std. Dev.*	2.55	2.65	2.10	2.52	2.47
Carbon Monoxide					
50	0.096	0.124	0.081	0.243	0.133
95	0.386	0.444	0.400	1.027	0.582
99	0.856	0.832	0.765	1.775	1.050
99.99	2.026	2.471	2.261	3.962	2.172
Std. Dev.*	2.11	2.02	2.23	3.57	2.04
Nonmethane Hydrocarbons					
50	0.048	0.079	0.064	0.151	0.058
95	0.224	0.288	0.257	0.527	0.234
99	0.397	0.435	0.417	1.007	0.412
99.99	1.554	1.330	2.002	3.983	1.734
Std. Dev.*	3.18	3.73	3.38	3.54	3.19

*Geometric standard deviation

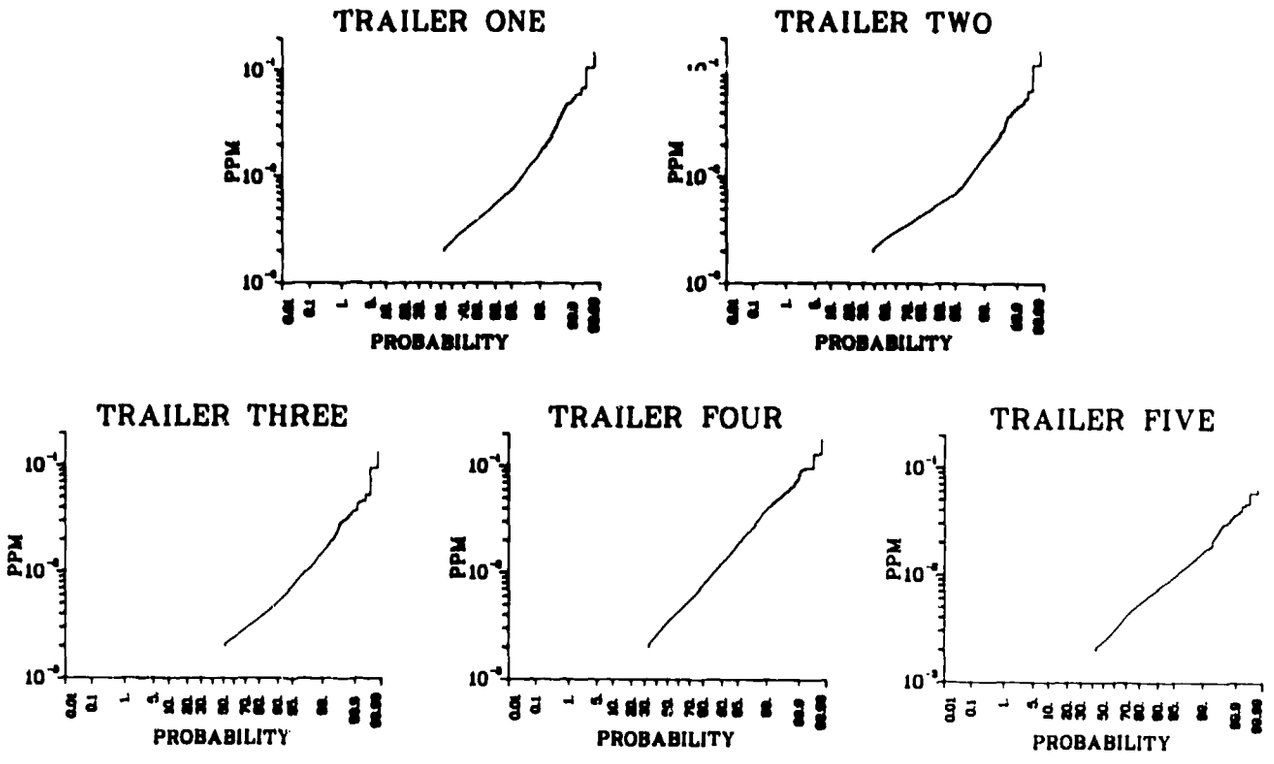


Fig. 7 - Cumulative frequency distributions of hourly average nitric oxide concentrations at WAFB, June 1976 - June 1977

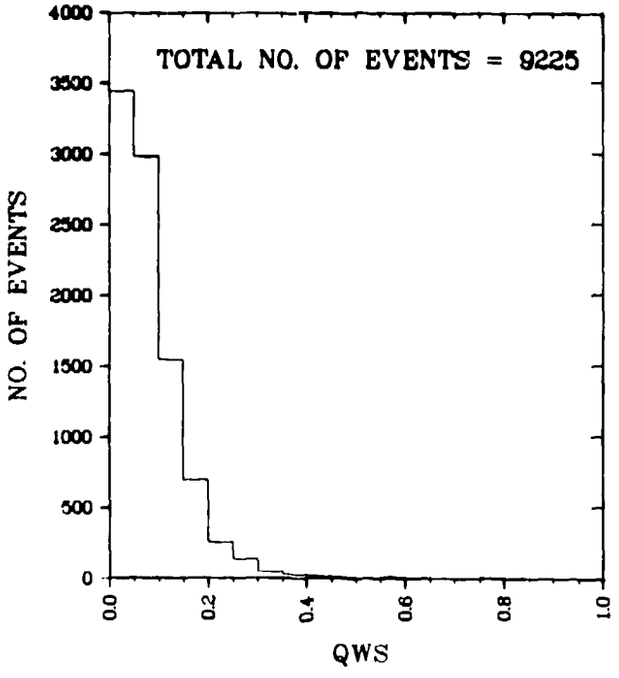


Fig. 8 - Wind speed q factor for WAFB Stations 1, 2, 3, and 5 combined, based on deviations of the wind speed from the four-station (Station 4 excluded) average wind speed, June 1976 - June 1977

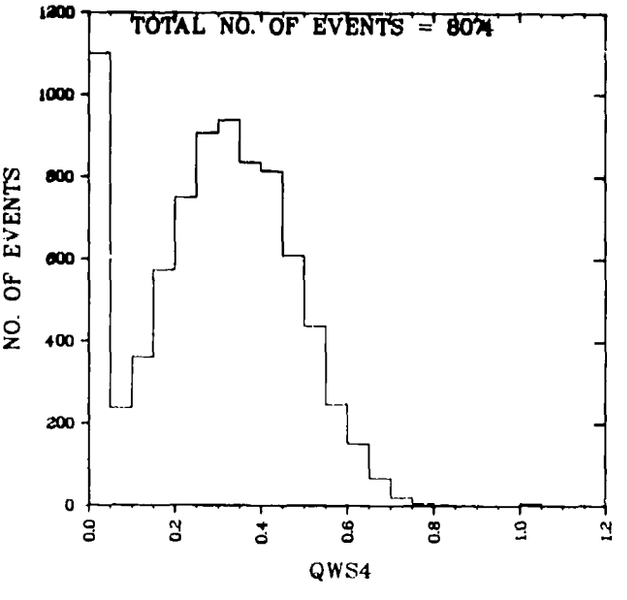


Fig. 9 - Wind speed q factor for WAFB Station 4, based on deviations of the wind speed from the four-station (Station 4 excluded) average wind speed, June 1976 - June 1977

respect to aerometric readings, but also with respect to meteorological measurements. Obviously, Station 4 should not be used as a reference station for defining the air base uniform wind field.

Another interesting feature of the meteorological data, i.e., the wind field, is the strong correlation between wind direction (and to a lesser extent, wind speed) and time of day. This is shown in Fig. 10, which is a scatter plot of hourly-average wind direction measurements at Station 2 vs. time of day. Such a strong wind-direction/time-of-day correlation has correspondingly strong implications for the air quality data dependence on time of day. More specifically, since the pollutant sources that are "seen" by a particular monitoring station are strongly dependent on wind direction, they are implicitly dependent on time-of-day. This dependence is, of course, superimposed on any time-dependent source emission rates that are characteristic of the sources.

EMISSION DATA - The discussion in this section is limited to Hypothesis #3 given on page 2 which states that the aerometric signals are correlated with the aircraft operations activity information. Apriori, one expects this hypothesis to be valid for monitoring stations located such that their received signals are dominated by the aircraft sources (provided, of course, that the stations are operating properly and the aircraft activity data are correct). Unfortunately, if the background pollutant concentrations (coming from nonaircraft sources) are dominant, as they tend to be at Williams Air Force Base, it is not at all clear whether this hypothesis should be valid for any of the stations. Figure 11, in fact, indicates that the carbon monoxide concentrations observed at Station 2 are indeed significantly correlated (at the 3 standard-deviation level) with hourly aircraft emission rates. Figure 12 shows the expected stronger correlation between computed carbon monoxide concentrations (using AQAM) and hourly aircraft emissions.

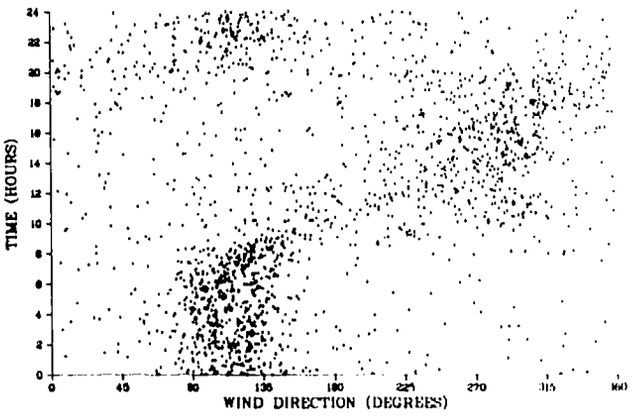


Fig. 10 - Wind direction at WAFB Station 2 versus time of day, June 1976 - June 1977

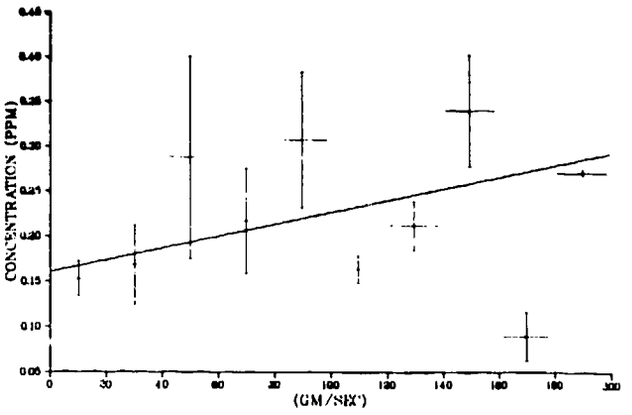


Fig. 11 - Observed carbon monoxide concentrations at WAFB Station 2 versus hourly aircraft emission rate at ground level, January 1977 daytime hours (6 am - 5 pm)

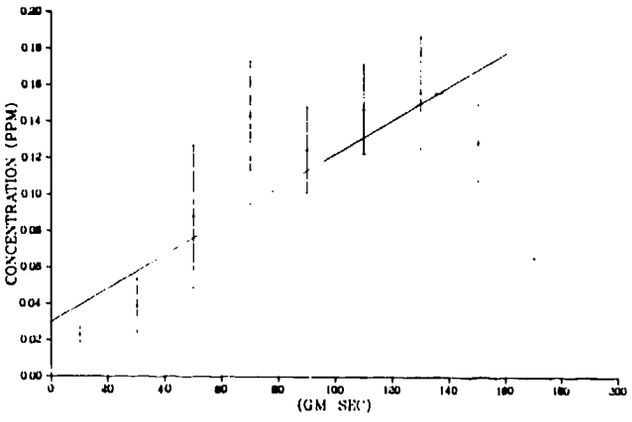


Fig. 12 - AQAM II predicted carbon monoxide concentrations at WAFB Station 2 versus hourly aircraft emission rate at ground level, January 1977 daytime hours (6 am - 5 pm)

MODEL TESTING

To date, only a limited amount of model testing has been done due to the late acquisition of the necessary AQAM input data. Examples for January, 1977, including comparisons between predicted and observed hourly CO, NO_x, and NMHC concentrations are presented here.

Because of the dominance of background pollutant levels over air-base-related levels, it would appear necessary to separate out the background contributions and base source contributions. There are several approximate methods of doing this, but none is completely free of faults. However, since environ sources are included in the emission inventory,

a direct comparison can be attempted between total observed pollutant concentrations and total predicted values. Scatter plots of total predicted vs. observed CO, NMHC, and NO_x concentrations are shown in Figs. 13, 14, and 15, respectively. The diagonal lines in the figures enclose predictions that are within a factor of two of the corresponding observations; these lines enclose approximately 40 to 50% of all the plotted points. This result is similar to model testing results obtained by authors who have tested short-term urban sulfur dioxide models in several cities, as reported in Ref. 17. What is particularly surprising about the predictions is that they are even in the same range as the observations, i.e., that all the points occupy a roughly square region of the scatter plot.

While the above results are encouraging, they do not address some of the more pertinent issues. The main objective in developing the AQAM was to simulate the air base, and especially the aircraft, contributions to air quality. Hence, some methods are needed to separate the total air pollutant levels into environ or background concentrations and the contributions of interest. These methods must be applicable to both the predictions and the observations. Of course, since the model requires an emission inventory on a source-by-source basis, it is easy to separate the background and air base sources and therefore, their contributions to the predicted air pollutant levels. But, such an approach obviously is not applicable to the observed air quality. The most promising approach is to remove the hourly "isotropic component" from each set of hourly station observations and predictions. This hourly isotropic component is defined as the arithmetic mean of the five-station observed ($\overline{C}_o$)

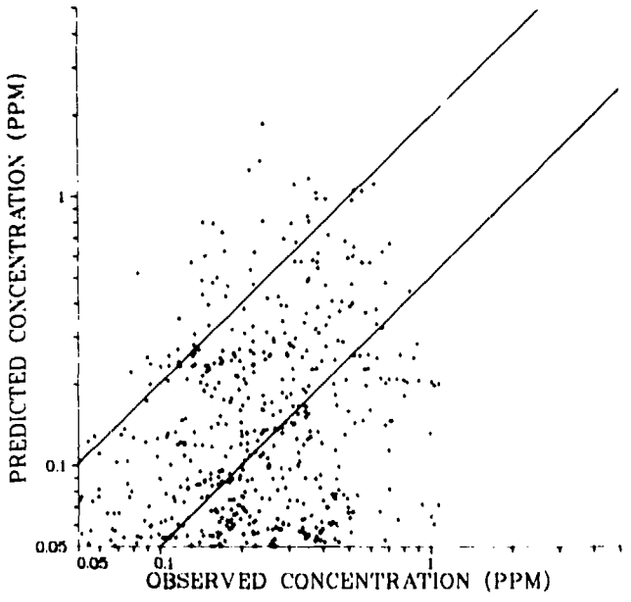


Fig. 14 - AQAM II predicted versus observed hourly average nonmethane hydrocarbon concentrations, WAFB, January 1977 - parallel lines indicate factor of 2 level of agreement

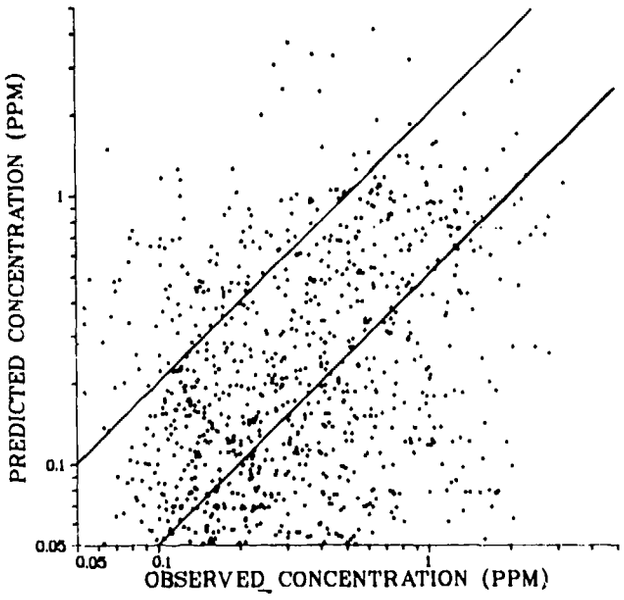


Fig. 13 - AQAM II predicted versus observed hourly average carbon monoxide concentrations, WAFB, January 1977 - parallel lines indicate factor of 2 level of agreement

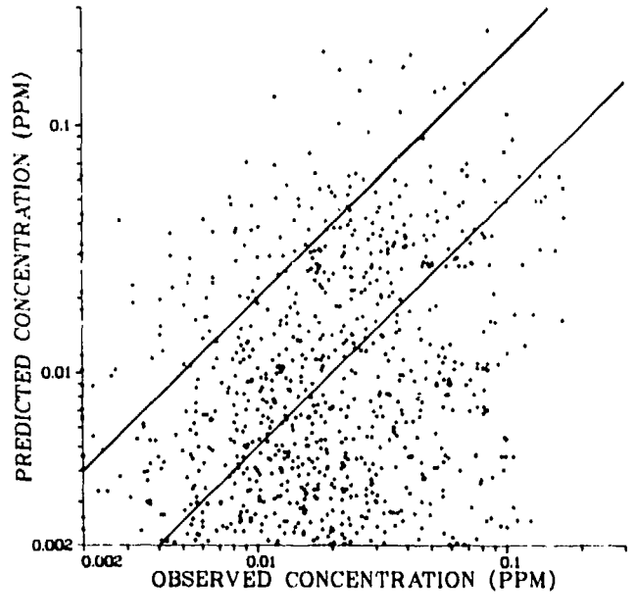


Fig. 15 - AQAM II predicted versus observed hourly hourly average NO_x concentrations, WAFB, January 1977 - parallel lines indicate factor of 2 level of agreement

and predicted ($\bar{C}_p$) concentrations. Removing this isotropic component from each hourly concentration results in observed and predicted values given by:

$$C_o' = C_o - \bar{C}_o$$

$$C_p' = C_p - \bar{C}_p$$

where C_o and C_p refer respectively to the total observed and predicted concentrations at the specified station, and the primed quantities refer to reduced (with isotropic components removed) concentrations.

The reduced concentrations can be both positive and negative. In fact, if the reduced predicted and observed concentrations are completely uncorrelated, both the magnitude and the signs of the C_o' and C_p' values would be randomly distributed relative to each other. More interestingly, and this is really the point of this approach, even if the total predicted and observed concentrations show a fairly high degree of correlation, because the local source contributions of interest are small, nothing can be said about how well the model actually simulates their contributions. On the other hand, since the major portion of the signals is removed, the reduced concentrations are much more sensitive to the local, i.e., aircraft and air base, sources. Hence, it is interesting to compare the quantities C_o' and C_p' directly. Figure 16 shows a scatter plot of the reduced carbon monoxide concentrations for January 1977. It is easy to see that the reduced concentrations are not randomly distributed relative to each other since the points have a strong preference for the first and third quadrants. This means that when a station has an observed concentration greater than the observed five-station mean, it also has a predicted concentration greater than the five-station predicted mean. This in turn implies that theory and experiment essentially agree on the pollutant rank ordering of the stations. Of course, there remains a considerable scatter of the points about the 45° line that would be the locus of all points if there was perfect agreement between theory and experiment.

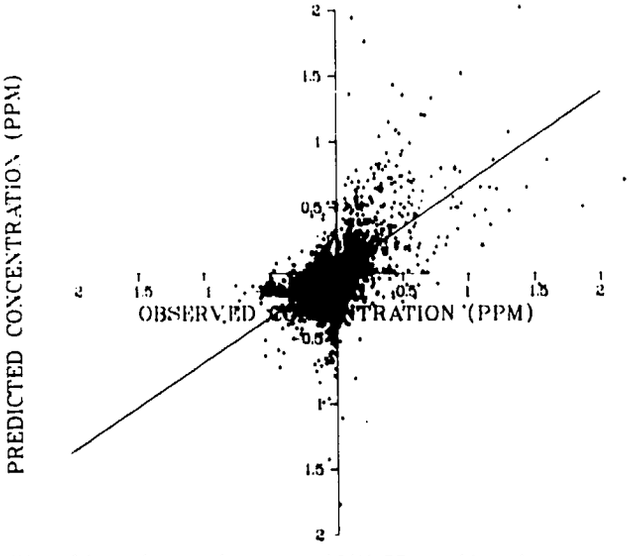


Fig. 16 - Observed versus AQAM II predicted "background subtracted" carbon monoxide levels January 1977 - background is defined separately for observed and predicted concentrations as the five-station arithmetic mean for the hour

CONCLUSIONS AND FUTURE WORK

Analysis of the air quality data obtained at Williams Air Force Base indicates that while the measured pollutant concentrations are generally very low, there does appear to be enough data with concentration [illegible] instrumental thresholds and lower accuracy limits to permit some model testing. Furthermore, a significant correlation exists (albeit a great deal of scatter) between hourly aircraft emissions and observed hourly pollutant levels, at least for carbon monoxide.

With respect to the meteorological data, the prime requirement that the wind field be spatially homogeneous seems to be satisfied a large fraction of the time, except at Station 4 which, because of its placement, produces anomalies in both wind field and aerometric data (relative to the other four stations).

Comparisons between total predicted and observed pollutant concentrations indicate that the model generates results in the correct concentration range and that about 40 to 50% of the predictions are within a factor of two of the corresponding observed values. Comparisons of reduced concentrations (individual station values minus five-station means) show that the theory and experiment essentially agree on the pollutant rank ordering of the stations.

Work during the coming year will test about 20 hypotheses regarding the data and compare observations with model predictions using the entire 13-month data set. Both the standard AQAM (called AQAM I for convenience) and a slightly more detailed model (called AQAM II) will be tested and compared to determine the relative merits of various model improvements. These improvements include more detailed treatment of aircraft taxiing operations, use of actual hourly aircraft activity data instead of statistically-distributed annual data, use of acoustic-sounder-determined mixing depths, incorporation of new algorithms for aircraft plume rise and low wind speed conditions, and use of modified turbulence parameters. Final reports will be prepared by September 1979.

REFERENCES

1. D.M. Rote and L.E. Wangen, "A Generalized Air Quality Assessment Model for Air Force Operations." U.S. Air Force Report AFWL-TR-74-304, Feb. 1975.

2. I.T. Wang, L.A. Conley, and D.M. Rote, "Airport Vicinity Air Pollution Model User Guide." U.S. Federal Aviation Administration Report FAA-RD-75-230, Dec. 1975.

3. Air Pollution Control District, County of Los Angeles, "Study of Jet Aircraft Emissions and Air Quality in the Vicinity of the Los Angeles International Airport." April 1971.

4. B.H. Willis, M.C. Diebert, and J.C. Barnes, "Analysis of Air Quality at Airports, Vol. III - The Measurements Program." Prepared by Environmental Research and Technology, Inc., under subcontract to Northern Research and Engineering Corp., for the Federal Aviation Administration under Contract DOT-FA71WA-2659, Nov. 1972.

5. M. Platt, J.C. Goodrich, and B.A. Egan, "Analysis of Air Quality at Airports, Vol. II - The Airport Model." Prepared by Northern Research and Engineering Corp. for the Federal Aviation Administration under Contract DOT-FA71WA-2659, Jan. 1973.

6. Geomet, Inc., "Model Verification - Aircraft Emissions Impact on Air Quality." U.S. Environmental Protection Agency Report EPA-650/4-74-049, Sept. 1974.

7. D.M. Rote, et al., "Airport Vicinity Air Pollution Study." Federal Aviation Administration Report FAA-RD-73-113, Dec. 1973.

8. J.T. MacWaters, R.C. Koch, and S.D. Thayer, "Air Quality Measured at Atlanta International Airport Before and During Experimental Aircraft Taxiing Operations." Geomet, Inc., Report EF-330, June 1974.

9. I.T. Wang, D.M. Rote, and L.A. Conley, "Airport Vicinity Air Pollution Study - Model Application and Validation and Air Quality Impact Analysis at Washington National Airport." Federal Aviation Administration Report FAA-RD-74-132, July 1974.

10. R.R. Cirillo, J.F. Tschanz, and J.E. Camaioni, "Airport Vicinity Air Pollution Study: The Impact of Modified Aircraft Taxi Procedures on Airport Air Quality." Federal Aviation Administration Report FAA-RD-74-212, Dec. 1974.

11. L.E. Wangen and L.A. Conley, "Air Quality Assessment Model Applied to Washington National Airport." Draft report prepared by Argonne National Laboratory for the U.S. Air Force, March 1975.

12. D.G. Smith et al., "Concorde Air Quality Monitoring and Analysis Program at Dulles International Airport." Federal Aviation Administration Reports FAA-AEQ-77-14 and FAA-AEQ-77-14A, Dec. 1977.

13. S. Yanagizawa, "Report of Overseas Research on Air Pollution Monitoring Systems." Prepared by Department of Engineering, Keio University, Japan (translation by Department of State, Division of Language Services, LS No. 62138, MF/ADS Japanese), March 1977.

14. P. Lorang, "Technical Support Report for Regulatory Action. Review of Past Studies Addressing the Potential Impact of CO, HC, and NO_x Emissions from Commercial Aircraft on Air Quality." Standards Development and Support Branch, Office of Air Waste Management, U.S. Environmental Protection Agency, Report AC-78-03, March 1978.

15. R.J. Yamartino et al., "Test Plan and Preliminary Analyses for the Accuracy Definition of the ANL/USAF Air Quality Assessment Model (AQAM)." Prepared by Argonne National Laboratory for U.S. Air Force (to be published).

16. D.C. Sheesley et al., "Williams Air Force Base Air Quality Monitoring Operations." Prepared by U.S. EPA and Northrop Corp. for U.S. Air Force and U.S. Navy (to be published).

17. K.L. Brubaker and D.M. Rote, "Dispersal Models for Sulfur Oxides in Urban Environments." In "Sulfur in the Environment: Part I, The Atmospheric Cycle," J.O. Nriagu, ed., John Wiley and Sons, Inc., 1978.

DISCUSSION

PANOFSKY: Quite often, when one finds the maximum of something in the middle of night it is because speed is a minimum then. Did you find anything like that, any diurnal variation of wind speed?

ROTE: There were a couple of things. The wind speed tended to be maximum in the middle of the day and quite light during the night. Also, it is a desert situation. You usually go from extremes of convective mixing in the day to very limited mixing at night and, in fact, you see the maximums very early in the morning and very late at night.

PANOFSKY: Do you think that might account for some of the diurnal maximums in pollution at night?

ROTE: Yes, that plus the wind direction variation, yes.

PANOFSKY: Any questions?

UNIDENTIFIED: How many aircraft operations per hour?

NAUGLE: That is a tremendous range from zero to, in the order of, 60 or 70 aircraft per hour.

This model treats it on an hour-by-hour basis.

UNIDENTIFIED: I would like to ask a general question and leave it to your discretion to apply it to station four.

In using a Gaussian dispersion formulation, is there any inherent preference for locations within the grid structure and, if so, is there any way to tune or adjust the calculating capacity of your model to get exact predictions for the site locations, assuming the site locations cannot be picked by the model?

ROTE: The way the model is set up, there is no discrimination for or against station placement or source location. As far as tuning the model is concerned, probably the only tuning that you could do that would be reasonable would be to look at the dimensions given to the source initially.

The model uses an approximation that treats each physical source as though it were initially contained in some finite volume, and the choice of that initial finite volume requires a fair amount of judgment.

There you can do some tuning. But, for example, if you are talking about an aircraft, once you have assigned an initial set of dimensions to the aircraft plume, you are stuck with that set of dimensions no matter where the aircraft is.

As for the effect of buildings, each source is treated either as a point, a line, or an area.

In the case of buildings, we generally treat the source. That is to say, if there are sources close enough to a building to be influenced by its height, we assign a dimension to that source that is commensurate with the size of the building and assume that, in fact, there will be height effects.

Again you have the freedom in that case to assign an initial set of dimensions that would approximate the height effects, but it is a very crude treatment to a very complex problem.

POLLUTION DISPERSION MEASUREMENTS AT HIGH ACTIVITY FLY-IN OF GENERAL AVIATION, MILITARY AND ANTIQUE AIRCRAFT

Howard Segal, Office of Environment and Energy

U.S. Department of Transportation
Federal Aviation Administration

ABSTRACT

General Aviation aircraft emissions have been measured at an extremely busy airfield with traffic levels in excess of 250 operations per hour. At no time were any significant levels of pollution detected, and no measurable effect of the airport upon the local community was seen. These measurements have permitted theoretical dispersion rates to be compared with actual measurements. Differences between actual and theoretical dispersion rates have been uncovered. These differences raise questions as to the accuracy of pollution models when they do not include aircraft-specific dispersion information.

CARBON MONOXIDE (CO) CONCENTRATIONS were measured during a major fly-in of general aviation (GA) and experimental aircraft at Lakeland Airport, Florida from January 23 thru 29, 1978. Over 3000 aircraft participated in this fly-in, where in excess of 250 aircraft operations per hour were experienced. The purpose of the measurements was to quantify the effect of emissions from GA aircraft on air quality under extreme conditions of airport activity. The Federal Aviation Administration (FAA), in conjunction with the Environmental Protection Agency (EPA), planned the measurement activity. Three FAA-owned Energetic Sciences "Ecolysers" (CO monitors) were used. EPA personnel participated in the field program and assisted in data gathering.

Figure 1 is an aerial view of the airport and the lightly populated surrounding countryside and Figures 2 and 3 show the operating pattern at the airport during easterly and westerly winds, respectively. Figure 4 shows the location of the 25 monitoring sites used at one time or another in the course of the data gathering. Measurements were made during aircraft landing, takeoff and taxi modes. Additionally, an instrument was set up in an auto which was periodically driven around the entire airfield at the periphery, in attempts to detect gross airport contributions to the local CO "background." Within the discriminating capability of the equipment this was not possible, nor were significant observable levels of CO measured during any of some 50 observed landings.

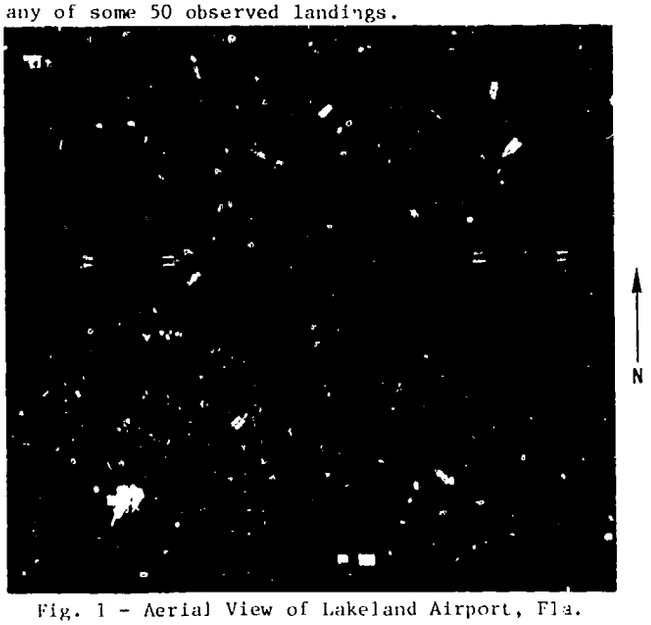


Fig. 1 - Aerial View of Lakeland Airport, Fla.

From all these measurements taken under a variety of airplane activity, and meterological conditions, the maximum projected one-hour average concentration measured at positions where people might be expected to be located was less than 2 parts per million (ppm) by volume. This concentration is insignificant (1)* when compared to the one-hour National Ambient Air Quality Standard (NAAQS) of 35 ppm. These measurements constituted one consideration in the formal recommendation by the EPA to withdraw GA engine emission standards (2).

Analysis of these measurements not only showed the small influence of GA aircraft on air quality but also for the first time quantified the dispersion rate from individual and groups of GA aircraft that were landing, taxiing and taking-off. Comparison of these measurements with theory indicates that some models may not account for the unique dispersion characteristics of the hot, turbulent airplane emission source.

*Numbers in parentheses designate References at end of paper

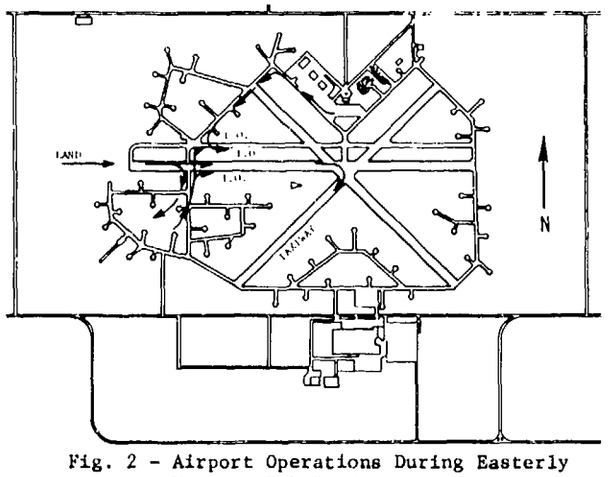


Fig. 2 - Airport Operations During Easterly Winds - Lakeland Airport

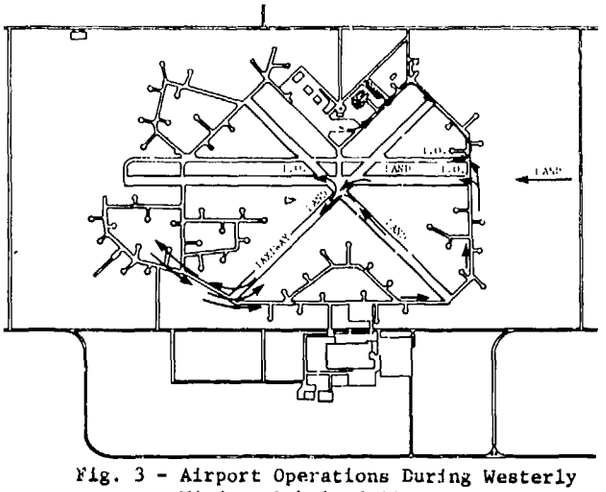


Fig. 3 - Airport Operations During Westerly Winds - Lakeland Airport

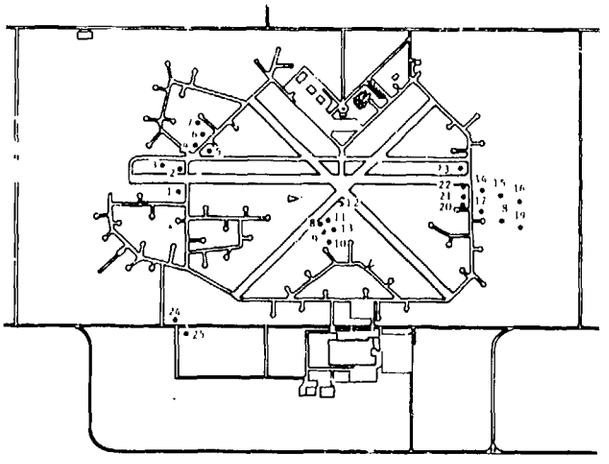


Fig. 4 - Monitoring Sites - Lakeland Airport January 23-30, 1978

APPROACH

To fulfill the need for mobile monitoring, Ecolysers and associated strip chart recorders were placed in the two automobiles used in this monitoring effort. By reinforcing the radio antenna with a dowel, and by attaching the air sampling tube to this dowel, an effective mobil air sampling system was devised. Figures 5 and 6 show this installation with the instruments placed inside and outside the automobile. Where a third monitoring site was required the installation shown in Figure 7 was used. Instruments were calibrated with 20 ppm calibration gas twice per day and before and after each major series of measurements.

The monitoring procedure was similar to the one used at Dulles International Airport to monitor Concorde Emissions (3,4). Three monitors were placed in a line abeam to the path of a taking-off or taxiing aircraft so that these instruments could sequentially detect the exhaust "plume" of aircraft emissions as the plume was transported by the wind over the three stations. In addition, as mentioned above, a car instrumented with an Ecolyser was periodically driven around the entire airport in attempts to detect the gross airport contribution to the local vicinity CO "background."

Measurements were also taken during landing, takeoff and taxi. Taxi measurements were made at both (multiple event) and low (single event) activity times.

Fig. 5 - Monitoring Installation - Inside Automobile

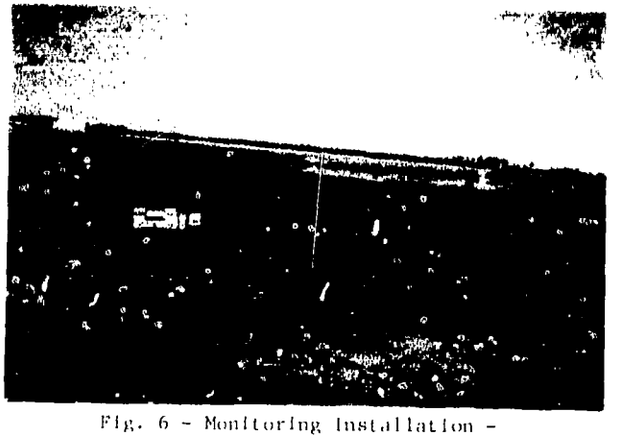


Fig. 6 - Monitoring Installation - Outside Automobile

Fig. 7 - Monitoring Installation - Non-mobile

RESULTS

LANDING MEASUREMENTS - On January 27, emissions from over 50 landing aircraft were measured at site 20. (Figure 4). Winds were from the north at 18 miles per hour (mph) and a "C" stability was estimated.

No concentration above background level was recorded at this site, located 450 ft. from the runway.

TAKEOFF MEASUREMENTS - On January 29, emissions from over 30 taking-off aircraft were measured at sites 20, 21 and 22. (Figure 4). Wind was from 330° at 12 mph and a "B" stability was estimated.

The strip chart trace from a typical taking-off GA aircraft is shown in Figure 8. Emissions from this modern GA aircraft are quite low.

However, at sites 20, 21 and 22, we also recorded the highest pollution levels of the entire week. This occurred when a World War II vintage B-25 took off. The strip chart trace of this takeoff is shown in Figure 9. These high emission levels from the large radial engines of this aircraft which were characteristic of both military and commercial aircraft of that time period are to be compared with the almost undetectable pollution produced by the turbine engines used in present day commercial aircraft (3,4). This comparison indicates that pollution has been drastically reduced by the aircraft industry in developing the gas turbine engine technology of the present era.

Dispersion measurements permit determination of the power law exponent to which atmospheric dispersion may be related. This dispersion rate has been measured during airplane taxi and takeoff and the relationship between concentration and dispersion can be expressed as:

$$C \propto X^{-K} \qquad (1)$$

where C is the concentration at downwind distance X. The rate at which the pollutant disperses is defined as K. Peak concentrations of those takeoff events having adequate signal to background ratio were averaged and were found to disperse as $X^{-1.9}$ in the power law expression listed above. This exponent which is derived from measurement data will be compared with the theoretical value of this exponent later on in the paper.

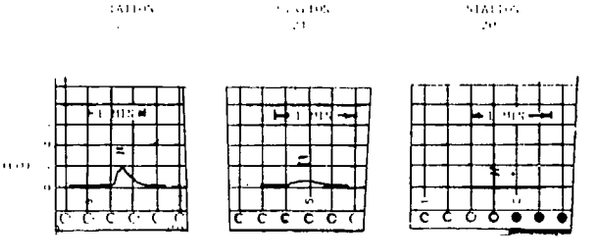


Fig. 8 - Trace of General Aviation Takeoff

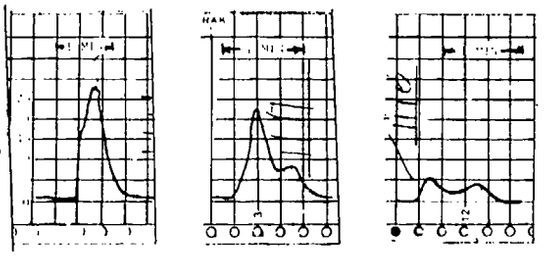


Fig. 9 - Trace of B-25 Takeoff

TAXI MEASUREMENTS (LOW ACTIVITY) - On January 26, emissions from over 40 taxiing aircraft were recorded. Wind was from 340° at 15 mph and a C stability was estimated. Pollution from this mode dispersed as $X^{-1.0}$ in the previously mentioned power law relationship

TAXI MEASUREMENTS (HIGH ACTIVITY) - The most noteworthy data were obtained at station 17, 18 and 19 between 1700 and 1740 hours on January 28, when a continuous queue of over 30 aircraft streched down the taxiway for more than 1/2 mile. Wind was from 345° at 12 mph and "D" stability was estimated. During peak activity one airplane taxied by the monitoring station every ten seconds. As they approached the end of the taxiway, these aircraft were almost continuously dispatched down the two takeoff runways at the rate of 278 aircraft per hour.

Because both taxi and takeoff emissions intermingled at the three monitoring stations downwind of the taxiing aircraft, it was necessary to devise a method for measuring emissions from the taking-off aircraft only. This was accomplished by moving the instrumented auto at site 18 to site 20 which is directly upwind of the taxiing aircraft. Takeoff concentrations were measured at this location. This move was made after sufficient data had been collected at site 18.

The contribution of takeoff emissions to concentrations at sites 17, 18, 19, and 20 was modeled and calibrated with measurements taken at site 20. This takeoff contribution was then subtracted from the total concentrations measured at sites 17, 18, and 19 to identify concentrations directly attributable to the taxiing aircraft. These data are plotted in Figure 10. Multiple event taxi emissions disperse as $X^{-0.4}$ in the power law relationship CoX^{-K}.

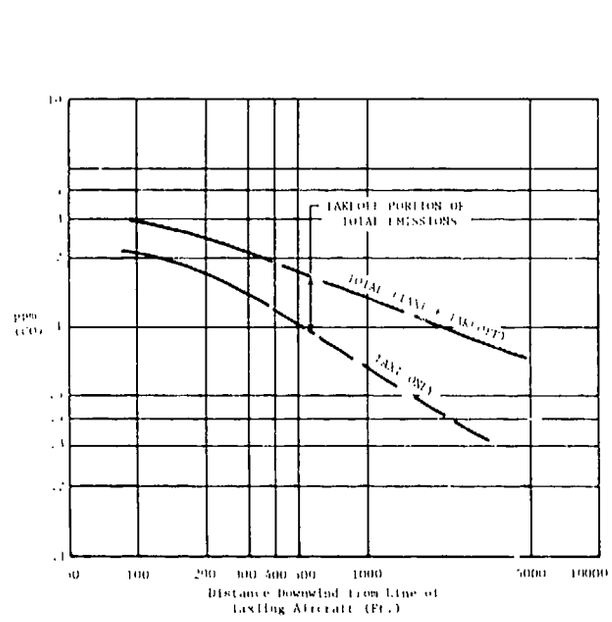


Fig. 10 - Dispersion of Carbon Monoxide from a Continuous Line of Taxiing and Taking Off General Aviation Aircraft, Lakeland Airport, Florida - January 28, 1978

CONCLUSIONS

The following conclusions may be drawn from the concentration summary of Table 1:

TABLE 1

CARBON MONOXIDE CONCENTRATIONS DURING DIFFERENT OPERATIONAL MODES

MODE	STABILITY CLASS	WIND SPEED (MPH)	CHARACTERISTICS PEAK CONCENTRATIONS (PPM ABOVE BACKGROUND)		
			SINGLE EVENT		1 HOUR AVERAGE
			DIST. 450 FT.	DIST. 335 FT.	DISTANCE 185 FT.
LANDING (SINGLE EVENT)	C	18	<1 PPM		
TAKEOFF (SINGLE EVENT)	B	12	<1 PPM*	21 PPM (B 25) 2 PPM (GA)	
TAXI (SINGLE EVENT)	C	15		<1 PPM	
TAXI (DURING QUEUE)	D	12			<2 PPM

* (COMMERCIAL JET FROM DULLES DATA, REF 4)

1. From all measurements taken under extreme aircraft activity conditions, the maximum recorded concentration for CO at the closest position where people might be expected to be located, was less than 2 ppm for a projected one-hour time period. This concentration is insignificant when compared to the one-hour NAAQS of 35 ppm.

2. The highest CO concentration ever recorded of the dispersing plumes of a taking-off airplanes (22 ppm at 335 ft. from the runway centerline) was measured at Lakeland Airport on January 29, 1978. This measurement, which was from a World War II vintage B-25, indicates that airplanes have been significant sources of CO pollution in the past. But, this problem is not present today, as is evidenced by the extremely low pollution levels of modern General Aviation aircraft (less than 3 ppm at 335 ft. from the runway) and the hardly detectable (less than 1 ppm) concentration one would expect from the highly efficient turbine engines of the present day commercial aircraft fleet.

The measured dispersion rates during taxi and takeoff in some cases do not coincide with the classical dispersion theory used in most airport models. This inconsistency is important to recognize, since it may contribute to errors in receptor concentrations calculated from airport pollution models. While this short terms measurement program was not designed to develop a large data base or to explain dispersion inconsistencies, (no measurements of the vertical propagation of the emission plume were made) the listing of the dispersion parameters in Table 2 is an initial quantification of a number of previously unmeasured dispersion characteristics.

Table 2

Mode	Approximate Aircraft Speed	Propeller Speed	Measured Power Law Exponent, k.	Theoretical* Power Law Exponent, k.
Taxi (Single Event)	15 MPH (Constant)	Low	1.0	1.8
Taxi (During Queue)	5 MPH (Constant)	Low	0.4	0.9
Takeoff	25 MPH (Accelerating)	High	1.9	1.8

*Derived From (5)

Factors contributing to the inconsistency between measurement and theory may be traced to the inability of the theory to effectively account for:

a. Plume rise

b. Extensive turbulent field created by the high velocity fan action of the propeller. (The extent and duration of this turbulent field is unknown at the present time.)

c. Different emission densities and turbulence intensity along the takeoff path of an accelerating aircraft.

ACKNOWLEDGEMENT

The author wishes to acknowledge the participation of Dr. Bruce Jordan and Mr. Wayne Fowler of the Environmental Protection Agency in this field measurement program and their contribution in accumulating the large amounts of data for this program.

REFERENCES

1. Federal Register, June 19, 1978, Part V, Environmental Protection Agency, 1977 Clean Air Act; Prevention of Significant Air Quality Deterioriation.

2. Federal Register, March 24, 1978, Part III Environmental Protection Agency, Control of Air Pollution from Aircraft and Aircraft Engines, Proposed Amendments to Standards.

3. H.M. Segal, "Monitoring Concorde Emissions" Journal of the Air Pollution Control Association, 27(7)623, July 1977.

4. D.G. Smith, R.J. Yamartino, C. Benkley, R. Isaacs, J. Lee, and D. Chang, "Concorde Air Quality Monitoring and Analysis Program at Dulles International Airport," (Final Report), Environmental Research and Technology, 696 Virginia Road, Concord, Massachusetts, 01742, Report No. FAA-EQ-77-14, December 1977.

5. D. Bruce Turner, Workbook of Atmospheric Dispersion Estimates, U.S. Department of Health, Education and Welfare, Public Health Service Publication #999AP26

DIS[illegible]

BOUBEL: I am concer[illegible]c your conclusion about the B-25 and genera[illegible]ion aircraft. I think if you look at the rel[illegible] displacement of the engines involved, you have got one order of magnitude, so I really don't think that is due to improved technology; I think it is due to the difference in the quantity of emissions coming from that particular aircraft.

SEGAL: I am citing just that was measured. For a more even comparison I think you can carry the reasoning one step further and relate the low emissions from a high-power jet aircraft such as the 747 to the high emissions from the high-power B-25. Carbon monoxide emissions during takeoff of a large modern jet aircraft such as the 747 are extremely low, many times lower than the emissions from even a small single-engine aircraft whose emissions are in turn lower than the emissions from a B-25.

DOWNIE: I wonder if you could explain what you mean by normal atmosphere.

SEGAL: If you look at the curves, let's say, in Turner's workbook, the slopes of those curves between B and E stability for Y and Z sigmas are almost identical, about 42 degrees. This comes out to a power-law exponent of 0.9. That is what I was referring to.

PASQUILL: You appear to be saying that theoretically you expect the concentration to fall off with distance to the power of 0.9 near 1 km from the line source, whereas you observe something very much slower than that. What is your explanation?

SEGAL: There are only two things that I can think of that would cause that. One would be plume rise, which would cause a flattening of it.

This would be sort of a curved function, and it would probably straighten out as you got further downwind. The second would be the turbulence from the source, which could be accounted for by assuming a new virtual source at an appropriate upwind distance.

UNIDENTIFIED: In other words, you are saying you should really have plotted those points at the nominal distance plus.

SEGAL: Exactly.

UNIDENTIFIED: The only other reason why you would expect a very low exponent would be if the actual dispersion conditions were very light.

SEGAL: Yes, thank you.

KEYNOTE SPEECH

BY

Ernest S. Rosenberg
Environmental Protection Agency

AIRCRAFT EMISSIONS AND AIR QUALITY

by
Ernest S. Rosenberg

U.S. Environmental Protection Agency
Washington, D.C.

I am here representing Dave Hawkins, EPA's Assistant Administrator for Air, Noise, and Radiation. Until late yesterday, Mr. Hawkins planned to be here, but a last minute fire fight made that impossible. He sincerely regrets being unable to appear before this conference, particularly because of how timely this meeting is in light of EPA's plans to amend the Federal Aircraft Engine Emission Standards.

As at least some of you undoubtedly know, the standards now in our regulations were issued in July of 1973 and were based on air quality analyses done for EPA during the 1971-1972 period. This past March, we proposed amendments to these 1973 standards and pointed out in the preamble to the Notice of Proposed Rulemaking that recent studies show that operations of small, privately-owned aircraft -- the general aviation segment of the industry -- are not significant contributors to air pollution, either on a regional basis or even on the basis of local impact in and around large general aviation airports. Accordingly, we proposed that standards applicable to such aircraft be rescinded. We further recognize that current pressures to improve the fuel efficiency of these types of aircraft will inevitably produce technological improvements in their engines which will result in reduced emissions of hydrocarbons and carbon monoxide as well as reducing fuel consumption -- without the administrative expense and interference of an emissions regulations program.

In contrast, our recent studies indicate that emissions caused by commercial aircraft operations at major air terminals still appear to be sufficient in magnitude to justify application of Federal standards to engines which power such aircraft. The strength of the air quality arguments supporting control of aircraft emissions do, however, vary with respect to the individual constituents of those emissions. Other speakers at this conference will, I am sure, go into considerably greater technical detail in this area than I can possibly do. Nevertheless, I can state that in view of the uncertainties attending the air quality impact of these different exhaust constituents, we intend to carry out additional studies in cooperation with the Federal Aviation Administration. We are hopeful that these studies will be completed around the summer of next year, 1979, and will permit final promulgation of revised standards later that year.

We recently scheduled public hearings on the Notice of Proposed Rulemaking we issued in March. Based on the information gleaned from those hearings, plus that provided to us in advance by those commenting on the proposal, we may find it possible to proceed with final rulemaking on some aspects of the proposed changes on an earlier schedule. However, it is clear that the special problems related to the resolution of the questions associated with oxides of nitrogen standards will make it impractical for EPA to reach a decision on aircraft engine NO_x emission standards until late next year.

A related EPA activity bearing on the justification for NO_x control, as mentioned by Mr. Jordan yesterday, is our program designed to produce a short-term ambient air quality standard for nitrogen dioxide, which, depending on the level chosen for promulgation, may bear on the need to control sources such as aircraft. On the other hand, it may not. Our current schedule for issuance of a short-term NO_2 standard would have us propose the standard by the spring of 1979.

I know that this conference is going to produce much new information for publication in the areas of both monitoring the various species of air pollutants at locations in and around large air terminals and in advanced mathematical modeling techniques for predicting pollutant concentration levels in such environs. I am certain that much has been learned in these areas since the 1971 studies which led to the current standards for aircraft engines were completed in response to the 1970 amendments to the Clean Air Act. I also suspect that much still remains to be done to develop mathematical prediction tools that have the complete confidence of the scientific community, particularly in the area of prediction of oxidant concentrations through models which recognize the complex atmospheric chemistry of photochemical oxidant formation. We believe, however, that the Nation and our Agency must proceed to make all possible progress in the reduction of the types of pollutants produced by aircraft and other sources, even in the face of technical deficiencies in the most up-to-date air quality modeling and monitoring techniques. In fact, decisions of this sort, the balancing of the need for a cleaner, more healthful environment against the desirability of proceeding with more complete, more sophisticated data, are a daily fact of life in agencies such as EPA.

With respect to the three pollutants of most current interest to aircraft operations -- hydrocarbons, carbon monoxide and oxides of nitrogen -- I will add a few remarks concerning the Nation's progress in achieving the ambient air quality standards required to be met by the individual states. The trend is perhaps most encouraging for carbon monoxide, for which the available monitoring data appear to be showing significant downward trends

for many metropolitan areas since the advent of nationwide motor vehicle emission standards in 1968. However, we are not out of the woods yet. Our most recent estimates show that 40 states plus the District of Columbia have not yet attained the national ambient air quality standards for carbon monoxide. Sixty-two of the largest 105 cities in the U.S. are still experiencing violations of the national ambient quality standards for carbon monoxide. Further, recent studies relating to effects of low concentrations of carbon monoxide on the health of persons experiencing coronary problems strongly support the current national air quality standards for carbon monoxide and suggest that it may indeed not be sufficiently strict.

With respect to the oxidant standard, the prospects for nationwide attainment of the national air quality standard is much less encouraging than for carbon monoxide. In fact all possible efforts must continue to be made to control small regional sources of hydrocarbon in many of the oxidant non-attainment areas in this country. The preamble to EPA's NPRM suggests that the cost effectiveness of hydrocarbon control modifications to aircraft engines is quite comparable to that associated with control of many other small hydrocarbon sources at the community level.

Considering nitrogen oxides, I mentioned earlier the complication introduced into the re-evaluation of the aircraft standards because of EPA's responsibilities under the 1977 amendments to the Clean Air Act to develop a short term NO_2 ambient standard. I can add that, while the nationwide attainment of ambient air NO_2 goals in terms of the present standard does not look as gloomy as that for oxidants, it is clear that effort toward NO_x control must continue. Progress has been made through automobile NO_x emission standards. However, the continued growth in emissions of nitrogen oxides from large stationary sources such as steam generation plants, gas turbines, gasoline and diesel engines used for community or industrial power generation needs, is overtaking the NO_x emission gains achieved by the Federal program to reduce NO_x emissions from motor vehicles. The current approximate 50-50 split between emissions of nitrogen oxides from mobile versus stationary sources is likely to be more like 30-70 by 1990.

EPA's present program of new source performance standards for stationary sources of oxides of nitrogen is being expanded. In the face of this expanded effort and the associated costs of pollution control equipment for large stationary sources, it would indeed be difficult for EPA to move too precipitously to reject programs for control of emissions from sources such as aircraft, when the technology is potentially available and has, as I understand it, been stimulated greatly through research support by the National Aeronautics and Space Administration.

We will of course be delving much more deeply into issues such as these in the forthcoming public hearings on the aircraft standards. Suffice it to say, that our evaluations of control strategies applicable to all sources certainly must include the technological information made available by conferences such as this one and we are indeed hopeful that the technology base relating to emissions impact from aircraft operations around large commercial airports will be much enhanced by your contributions during these three days.

I will conclude my prepared remarks at this point. Again, I appreciate the chance to share the foregoing thoughts with you today and will attempt, with Mr. Kittredge's assistance, to respond to any questions you may have.

AIR QUALITY MODELING

Chairman: D. M. Rote
University of Chicago

ATMOSPHERIC DISPERSION MODELING

F. Pasquill
37 Arbor Lane, Winnersh
Wokingham, Berks. RG11 5JE
England

1. THE CURRENT STATE OF POINT-SOURCE-PLUME MODELING IN PRACTICE

The science of atmospheric dispersion modeling, especially as applied to the point-source-plume, has been the subject of active review over the last few years. Notably there have been expert reviews in the U.S.A. by F.A. Gifford (1,2), discussing the popular methods of estimating the conventional dispersion parameters σ_y and σ_z (the Pasquill-Gifford curves, the Brookhaven ASME curves and the TVA curves), with special reference to the inconsistencies of these methods and their limitations in application to the real flows which in various ways do not conform to the ideal form assumed. Then there have been several discussions (3,4,5,7) of the basis of dispersion estimates for idealized atmospheric boundary layer flow, as provided by various theoretical approaches. Furthermore, with the object of obtaining a broader concensus on the present position in the practical applications, the American Meteorological Society last year organized a workshop, the report on which (6) goes a long way toward clarifying much of the confusion that has persisted. Most recently the World Meteorological Organization has held a comprehensive symposium on the various aspects of boundary layer science relevant to air pollution (16), including some contributions on dispersion in hilly terrain, a subject which has also been reviewed separately and on which active research combining theory and wind tunnel model observations is in process (13,14).

With the existence of such recent reviews it is not proposed to embark on yet another comprehensive account at the present stage, and in the writer's view the most useful steps for the present conference would be to list the recent references, to underline currently outstanding developments, and to note features which seem specially relevant to the dispersion of pollution released at airports. For the second of these contributions it is hoped that the compact summary offered in Table 1, which is set out in terms of the P-G system, will be a helpful guide to the main points of the fundamental basis.

2. RECENT RECOMMENDATIONS FOR MODIFICATION OF THE P-G SYSTEM

As a consequence of the various considerations referred to in Table 1 certain recommendations have already been made for modification of the P-G system or for adjustment of the σ - estimates thereby provided. Some of these are quite specific (6) and are summarized below with some additional remarks.

(a) Crosswind spread should preferably be estimated from a knowledge of the σ_θ (the standard deviation of the fluctuation of wind direction) actually applicable to the conditions of terrain and airflow. There is nothing fundamentally new in such a procedure, which was in fact included in the original development from which the P-G system sprung, but there has always been an unfortunate though understandable reluctance to undertake the special measurements and analyses required. An appropriate working formula is

$$\sigma_y/\sigma_\theta x = f(x) \qquad (1)$$

the function $f(x)$ being unity as x (the distance downwind) approaches zero and falling off with increasing x in a manner which has not yet been prescribed entirely satisfactorily but which is roughly as follows:

x(km)	0.0	0.1	0.2	0.4	1	2	4	10	10	
f(x)	1.0	0.8	0.7	0.65	0.6	0.5	0.4	0.33	$0.33(10/x)^{\frac{1}{2}}$	(2)

For further details and qualifications of the procedure Ref. (4), Table 2 and Ref. (6) should be consulted.

(b) An additional crosswind spread arises from the turning of wind direction with height, to an extent which seems unlikely to be important for distances less than about 10 km, and a rough rule that has been suggested (4) for $x \geq 20$ km is

$$\sigma_y^2 = \sigma_{yt}^2 + 0.03\Delta\theta^2 x^2 \qquad (3)$$

where the first term of the sum is due to the crosswind component of turbulence and is calculated by the procedure in (a), and the second term is the contribution from a turning of $\Delta\theta$ radians over the whole depth of the plume.

(c) Although certain details still remain to be settled it is now possible to begin to envisage the format of a new set of curves for σ_z, in which the dependence on distance, roughness of terrain and atmospheric stability will be more realistically and comprehensively represented than hitherto. One such format has already been suggested (5) on the basis of the latest guidance available from Monin-Obukhov similarity, Surface Rossby number similarity, and Deardorff mixed-layer similarity.

(d) The P-G curves and the generalizations referred to in (c) are applicable to a surface

release of pollution. There has been much debate about the effect of elevation of the source, and in Ref. (6) the well-known Brookhaven curves which appear in Ref. (8) are declared to be ' an appropriate choice when σ_z is less than the effective source height H '. This is a perfectly reasonable view in that the curves are a representation of measurements of the ground-level concentrations arising from a passive elevated source, but it should be kept in mind that those measurements are samples of behaviour over a particular site and that a demonstration of their conformity with a general theory has not been provided. Alternatively, it is the writer's view and also a recommendation of Ref. (6) that where possible a formula analogous to that in (a) for σ_y should be applied, using data on the fluctuation of wind inclination at the height of the source. Although the form of the distance function f(x) is in this case even less well defined than for crosswind spread, it does have the same limiting value of unity as $x \to 0$. This result, together with the simple principle that when σ_z/H becomes large enough the concentration distribution must approach that appropriate to a surface release, provides a basis for an interpolation procedure which should give a realistic estimate at intermediate values of σ_z/H also. In a new system (17) just completed in the Meteorological Office use is made of the K-treatment for vertical spread, with K a function of height (in accordance with the latest generalizations on turbulence in the boundary layer) and also a function of time of travel from an elevated source, such that in effect the rate of spread is in accordance with statistical theory as $x \to 0$, as proposed above.

(e) So far reference has been confined to passive releases, but of course when the effluent rises bodily, from initial momentum or more important still under the action of buoyancy, a spreading process is induced by the relative motion of the plume and the ambient air. As discussed previously (Ref. (7), p. 271) the addition to 'passive source' diffusion may be important and even dominant to begin with, especially in stable conditions when the spread under the action of atmospheric turbulence is small or negligible. Based on this discussion a rough rule has been suggested (and was incorporated in Ref. (6)) in the form

$$\sigma_z^2 = \sigma_{zt}^2 + \Delta H^2/10 \qquad (4)$$

the first term in the sum referring to a passive release and the second to the induced spread of a rising plume at height ΔH above the level of release.

3. SOME REMARKS ON THE SPECIAL ASPECTS OF THE DISPERSION OF POLLUTION FROM AIRPORT SOURCES

In many respects the plume dispersion estimates that can be made on the foregoing lines are just as applicable to the pollution from airport sources as they are to that from urban sources. There are likewise certain limitations common to both circumstances, notably

(a) lack of homogeneity in the roughness of the terrain,

(b) prevalence of wakes from buildings.

Factors special to the airport case are

(c) the multi-jet form of the aircraft sources

(d) the wake of the releasing aircraft and those of neighbouring aircraft, and

(e) the 'near-instantaneous line source' form of the release during take-off and landing.

Items (c) and (d), which may be the subject of review by others at this conference, will both contribute a dispersive action additional to that imposed by an idealized boundary-layer flow on a passive point-source release. This additional spread will presumably initially be over a height and width essentially determined by the dimensions of the aircraft and of any other vigorous wakes that happen to be nearby. So in round figures the cross-section encompassing the exhaust from a modern jet might be expected to be initially say 10 m in the vertical and 30 m across. Now for a passive release in an idealized boundary-layer flow, with the general roughness of an airport area, vertical and lateral spreads of this magnitude would be achieved 'naturally' at downwind distances in the region of 50 m in neutral conditions, and at shorter or longer distances in unstable or stable conditions respectively. This suggests that for the overall level of pollution on or downwind of an airport area the idealized σ - estimates are unlikely to be seriously in error except close in to the individual sources or in the most stable conditions.

In respect of item (e), if the take-off or landing wind conditions are ideal, i.e. with direction along the runway, the release will be in the form of a near-instantaneous alongwind line source. However, this does not mean that the most appropriate estimate of crosswind spread will be that for an instantaneous point source, for in reality the distribution of the release alongwind will introduce effects similar to those that occur when the release is maintained at a fixed point, and the time-mean spread at a downwind receptor will tend to be similar to that for a continuous release over a time X/u where X is the length of the aircraft track and u the wind speed. On the other hand, if the wind is significantly across the runway a near-instantaneous crosswind line source will be produced, for which crosswind spread will at first be ineffective and the controlling spread will be that in the vertical, at a rate which again will tend to be that appropriate to a continuous release.

The need for detailed modeling of the special nature of the aircraft releases should in any case be considered realistically in the light of the accuracy which is achievable as well as that which is required. To that end useful rough estimates of expected time-mean concentrations might first be attempted on relatively simple lines with the following steps:

(f) definition of the area of effective release (i.e. that covered by taxi-ing routes and the runways in operation),

(g) averaging over that area the known or expected exhaust emissions appropriate to the aircraft operations over specified periods,

(h) treatment of dispersion from the area

source so defined on conventional lines, adopting the idealized estimates of σ_z (and of σ_y if required) as reasonable approximations except close in to the aircraft tracks - 'close in' meaning distances ranging from say 50 m in daytime (good mixing) conditions to some hundreds of metres in stable conditions.

Finally, it should be kept in mind that the most serious occasions of local pollution will as usual be in calm conditions, for which the plume model is unrealistic. Then the most useful approach might be to estimate the order of magnitude of the concentration build-up that would follow on the assumption of horizontal confinement within the airport area, with

(i) in stable conditions an assessment of the effective vertical spread resulting from the rise of the buoyant exhaust,

(j) in convective conditions estimates of the time-rate of vertical and horizontal dispersion in accordance with Deardorff's mixed-layer similarity.

4. REFERENCES

1. F.A. Gifford, "Atmospheric Dispersion Models for Environmental Pollution Applications. Lectures on Air Pollution and Environmental Impact Analyses", American Met. Soc., 1975, p. 35-58.

2. F.A. Gifford, "Turbulent Diffusion-Typing Schemes: A Review; In Consequences of Effluent Release", Ed.R.L. Shoup, Nuclear Safety, 17, No. 1, 1976, p. 68-86.

3. F. Pasquill, "The Dispersion of Material in the Atmospheric Boundary Layer - the Basis for Generalization. Lectures on Air Pollution and Environmental Impact Analyses", American Met. Soc., 1975, p. 1-34.

4. F. Pasquill, "Atmospheric Dispersion Parameters in Gaussian Plume Modeling. Part II, Possible Requirements for Changes in the Turner Workbook Values", EPA-600/4-76-030b, 1976.

5. F. Pasquill, "Dispersion from Individual Sources", (in press) Proc. ASTM Meeting, Boulder, 1977. Also in Amended Form with Appendices, under title, "Atmospheric Dispersion Parameters in Plume Modeling", 1977 Review, EPA-600/4-78-021, 1978.

6. American Met. Soc., "AMS Workshop on Stability Classification Schemes and Sigma Curves - Summary of Recommendations", 1977, Bull.Am.Met.Soc., 58, No. 12, p. 1305-1309.

7. F. Pasquill, "Atmospheric Diffusion", 2nd. Edn., Chichester, Ellis Horwood Ltd.; New York, John Wiley & Sons, 1974.

8. M.E. Smith, (Ed.), "Recommended Guide for the Prediction of the Dispersion of Airborne Effluents", Am.Soc.Mech.Eng., New York, 1968.

9. G.A. Briggs, "Plume Rise", U.S. Atomic Energy Commission, Div. Tech. Inf., 1969.

10. D.B. Turner, "Workbook of Atmospheric Dispersion Estimates", U.S.D.H.E.W., Environmental Health Service, revised 1970.

11. H.A. Panofsky, H. Tennekes, D.H. Lenschow and J.C. Wyngaard, "The Characteristics of Turbulent Velocity Components in the Surface Layer Under Convective Conditions", Boundary-layer Meteor., 11, 1977, p. 355-361.

12. G.E. Willis and J.W. Deardorff, "A Laboratory Model of Diffusion into the Convective Planetary Boundary Layer", Quart.J.R.Met.Soc., 102, 1976, p. 427-446.

13. B.A. Egan, "Turbulent Diffusion in Complex Terrain. Lectures on Air Pollution and Environmental Impact Analyses", American Met. Soc., 1975, p. 112-135.

14. J.C.R. Hunt and W.H. Snyder (in preparation).

15. A.H. Weber, K.R. McDonald and G.A. Briggs, "Proc. Joint Conf. on Applications of Air Pollution Meteorology", American Met. Soc., 1977, p. 96-102.

16. WMO Report No. 510, "Symposium on Boundary Layer Physics Applied to Specific Problems of Air Pollution", 1978.

17. F.B. Smith, "The Application of Field Experiment Data to the Parameterization of Dispersion of Plumes from Ground-Level and Elevated Sources", Institute of Mathematics and its Applications. Conference on Mathematical Modeling of Turbulent Diffusion in the Environment, 12-13 September 1978, Univ. of Liverpool, 1978.

Table 1-Synopsis of Present Position in the Generalized Estimation of Plume Dispersion Parameters in an Idealized Atmospheric Boundary Layer

	Effect	Qualification of P-G estimate	Basis for possible change
Crosswind spread σ_y	Roughness & Sampling time	z_o = 3 cm 3 min	Statistical theory and explicit use of wind fluctuation data (4,7) providing σ_θ for particular roughness and sampling time.
	Thermal stratification	Based on limited climatology of σ_θ	(a) Use of σ_θ (4,6,7) measured or estimated from a similarity relation such as that of Panofsky et al. (11) (b) In very unstable conditions, Deardorff laboratory model for windless convection. (5,12)
	Turning of wind direction with height	No allowance	Semi-theoretical treatment of vertical diffusion-shear interaction (7).
Vertical spread σ_z	Roughness	z_o = 3 cm	Lagrangian Monin-Obukhov similarity for surface layer (3,5).
	Spread in upper part of near-neutral boundary layer	Largely subjective extrapolation	K-treatment using K profile generalized through Surface Rossby number similarity (5).
	Thermal convection	Empirical guidance, especially from Prairie Grass dispersion study	(a) Lagrangian Monin-Obukhov similarity for short range (5), Deardorff similarity and laboratory model thereafter (5,12). (b) 2nd-order closure treatment (5).
	Nocturnal stability	As for convection	(a) Lagrangian similarity plus empirical guidance (5,15). (b) Semi-theoretical considerations of reduction of mixing depth. (c) 2nd-order closure treatment.
	Elevation of source	No allowance	(a) Guidance from experimental surveys (8). (b) Interpolation between statistical theory for short range and Lagrangian similarity/K treatments for surface release and longer range. (c) 2nd-order closure treatment (5).
	Spread induced by plume rise	No allowance	Dimensional considerations of plume rise and experience with power plant plumes (7,9).
	Vertical distribution	Assumed Gaussian	In the relation for variation of concentration with height, $C(z)/C(0) = \exp(-az^n)$, theory and observation (3,7) suggest that at short range from a surface release n is in the range 1.0 - 1.5, not 2 as in Gaussian.

DISCUSSION

D. SMITH: At the early part of your talk, you mentioned the desirability of understanding the phenomena that you are dealing with, and at times really going into more detail, for example the σ_θ analysis. Does that lend some persuasion to continuing to pursue approach No. 2 at the present time, considering the modest availability of data for the large ensemble averages that might exist in this particular area?

PASQUILL: Yes. I am not saying that one shouldn't do the sort of studies and analyses that were involved in Item 2, or that were involved in fact in all that I have been talking about this morning.

What I am really saying is that one can attempt to improve and refine progressively as one goes on. Having done that, then you have to ask yourself the question, now that I know so much about the dispersion process and what the relations are, with the available parameters or the parameters that can be measured, then what are the uncertainties that inevitably arise in the estimation of concentration, and on that basis, therefore, how much detail do I want in my engineering model?

You may have to do some experiments to decide how far to go and what model to use. You may have to go into these detailed models, but that doesn't say that you have necessarily to use them in an operational sense.

SEGAL: General Motors did some testing of a number of cars in Detroit, and they came up with some curves. What they show is a suppression for up to a hundred meters of the stability range, the stable versus unstable.

That was for a hundred meters. I'm sure you don't want to extrapolate that out, but I'm sure you would want to consider the situation up to a thousand meters, which is the airplane case. It makes a big difference in the answer maybe a factor of ten in the concentration.

My question is do you have any sort of guidance you could give as to how you could extrapolate a turbulent source, turbulence introduced to some larger distance, so that you could perhaps get a different dimension as to what sigma to use, the σ_z and the σ_y?

PASQUILL: You are asking how do you allow for the decay of the extra turbulence that arises for one reason or other at the source.

SEGAL: When is the transition, if there is a transition?

PASQUILL: It is very difficult to put one's finger on that. When I used to do chemical warfare studies and do measurements in the field, people would say if there are some obstructions in the terrain, you go, well, 30 diameters down wind, and then you can forget about it. That was the sort of guess that was made in those days.

I think the answer to your question very largely must come from physical modeling experiments. What you are really saying is what is the property of the wake which is associated with the source? I think you will get your best answer to that from physical model studies.

POTENTIAL EFFECTS OF COMMERCIAL AVIATION ON REGION-WIDE AIR QUALITY IN SAN FRANCISCO BAY AREA

William H. Duewer and John J. Walton

Lawrence Livermore Laboratory, University of California,
Livermore, CA 94550

ABSTRACT

The use of the LIRAQ-2 model in projecting the potential effects of a doubling or halving of emissions from commercial aircraft on Bay Area air quality is described and the results are discussed.

DESCRIPTION OF THE MODEL

THE LIVERMORE REGIONAL AIR QUALITY (LIRAQ) models were developed when, through the Research Applied to National Needs (RANN) program, the National Science Foundation supported a 2 1/2-year interagency effort by the University of California Lawrence Livermore Laboratory (LLL), the Bay Area Air Pollution Control District (BAAPCD), and the NASA Ames Research Center (ARC) to develop and validate the LIRAQ-1 and LIRAQ-2 models. These codes are deterministic two-dimensional Eulerian grid air-quality models that compute spatial and temporal distributions of significant air pollutants from specified emissions, meteorological conditions, topography, and initial boundary concentrations.

LIRAQ-1 and LIRAQ-2 are described in a User's Guide (1),* a two-volume report (2,3), and two journal articles (4,5). The models have been further described to the potential user community at an NSF funded workshop (6), by a NSF funded review (7), and in a comparison with the Urban Airshed Model (8). LIRAQ-1 deals with chemical species that are not strongly affected by chemical reactions and uses the flux-corrected transport scheme of Boris and Book (9). LIRAQ-2 treats chemically reactive species, but uses simple upstream differencing to treat the transport. For this report only LIRAQ-2 was used.

In 1976, LLL entered into an interagency agreement with the U. S. Environmental Protection Agency (EPA) to modify and extend the LIRAQ models to include sulfur species (SO_2 and sulfates) and to prepare data processors for the necessary input files to be developed from EPA Regional Air Monitoring Station (RAMS) data tapes so that the LIRAQ models could participate in the Regional Air Pollution Study (RAPS). In part, this is described in (10).

Because detailed descriptions of the model have been provided in the several LLL reports and two journal articles cited above, no detailed description will be provided here except for material that has been changed since 1975.

It will be noted that the chemical reaction mechanism used in LIRAQ-2 was changed in 1976 as part of the work done for EPA, and it was the only recent change in the model that caused a significant alteration in numerical results. The reaction mechanism developed in 1976 uses several reaction rate constants that would be evaluated differently in 1978 than they were in 1976. These differences in rate coefficients would reflect recently published laboratory measurements. The mechanism actually used is given in Table 1. Other recent changes in LIRAQ-2 affect I/O format, the file management scheme, and some relatively minor aspects of model initialization.

As part of the NSF contract, the models were verified for three days in the San Francisco Bay Area; two additional days have since been studied by the BAAPCD as part of the development of an Air Quality Maintenance Plan (AQMP) (11). The model verification studies for the Bay Area have demonstrated several model sensitivities, and provide a basis for the evaluation of model performance.

Table 1 - Reactions in the photochemical submodel.

Reaction	Arrhenius parameters[a] A, cm^3/s	C,K
Photolysis[b]		
$O_3 + h\nu \rightarrow O + O_2$		
$O_3 + h\nu \xrightarrow{H_2O} O_2 + 2OH$		
$NO_2 + h\nu \rightarrow NO + O$		
$NO_3 + h\nu \rightarrow NO_2 + O$		
$HNO_2 + h\nu \rightarrow HO + NO$		
$H_2O_2 + h\nu \rightarrow 2OH$		
$HC_4 + h\nu \rightarrow RCO_3 + HO_2$		
$HC_4 + h\nu \rightarrow CO$		
O_x-NO_x-HO_x Reactions		
$O + O_2 + M \rightarrow O_3 + M$	1.07×10^{-34}	510
$O_3 + NO \rightarrow O_2 + NO_2$	1.0×10^{-12}	-1200
$O + NO + M \rightarrow NO_2 + M$	4.0×10^{-33}	940
$O + NO_2 \rightarrow NO + O_2$	9.1×10^{-12}	0
$O + NO_2 + ZM \rightarrow NO_3 + ZM$	3.5×10^{-32}	300
$O_3 + NO_2 \rightarrow NO_3 + O_2$	1.1×10^{-13}	-2450
$NO_2 + NO_3 \rightarrow N_2O_5$	3.8×10^{-12}	0

*Numbers in parentheses designate References at end of paper.

Table 1 - Continued

Reaction	Arrhenius parameters[a] A, cm^3/s	C,K
$N_2O_5 \rightarrow NO_2 + NO_3$	$5.7\times10^{+14}$	-10600
$NO + NO_3 \rightarrow 2NO_2$	8.7×10^{-12}	0
$N_2O_5 + H_2O \rightarrow 2HNO_3$	3.0×10^{-16}	-3300
$HO + NO_2 \overset{M}{\rightarrow} HNO_3$	1.0×10^{-11}	0
$HO + NO \overset{M}{\rightarrow} HNO_2$	6.0×10^{-12}	0
$HO + CO \rightarrow CO_2 + HO_2$	1.4×10^{-13}	0
$HO_2 + NO \rightarrow HO + NO_2$	1.0×10^{-11}	-350
$HO + HO_2 \rightarrow H_2O + O_2$	2.0×10^{-11}	0
$HO_2 + 2NO_2 \rightarrow HNO_2$	2.0×10^{-14}	0
$HO_2 + O_3 \rightarrow HO + 2O_2$	6.0×10^{-14}	-1220
$HO + O_3 \rightarrow HO_2 + O_2$	1.6×10^{-12}	-1000
$HO + HNO_3 \rightarrow H_2O + NO_3$	9.0×10^{-14}	0
$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$	1.7×10^{-11}	-500
Reactions of HC_1		
$HC_1 + O \rightarrow RO_2 + RCO_3$	1.0×10^{-11}	-360
$HC_1 + O_3 \rightarrow HO_2 + RO + HC_4$	7.0×10^{-15}	-1900
$HC_1 + HO \rightarrow RO_2 + HC_4$	4.0×10^{-11}	-120
$HC_1 + HO \rightarrow RO_2 + H_2O$	3.0×10^{-11}	-350
$HC_1 + NO_3 \rightarrow NO_2 + H_2O$	5.0×10^{-13}	-1400
$HC_1 + HO_2 \rightarrow HO + HC_2$	0	0
Reactions of HC_2		
$HC_2 + O \rightarrow RO_2 + HO$	3.2×10^{-11}	-2000
$HC_2 + HO \rightarrow RO_2 + H_2O$	4.5×10^{-11}	-900
Reactions of HC_4		
$HC_4 + HO \rightarrow RCO_3 + H_2O$	1.5×10^{-11}	-350
$HC_4 + O \rightarrow HO + RCO_3$	3.2×10^{-12}	-900
$HC_4 + HO_2 \rightarrow H_2O_2 + RCO_3$	8.0×10^{-13}	-3700
$HC_4 + HO \rightarrow CO + HO_2 + H_2O$	3.0×10^{-11}	-350
$HC_4 + NO_3 \rightarrow RCO_3 + HNO_3$	3.0×10^{-15}	-900
$HC_4 + RO_2 \rightarrow ROOH + RCO_3$	8.0×10^{-13}	-3750
Reactions of SO_2		
$HO_2 + SO_2 \rightarrow HO + SO_4^=$	9.0×10^{-16}	0
$HO + SO_2 \rightarrow HO_2 + SO_4^=$	6.0×10^{-13}	0
$RO + SO_2 \rightarrow HO_2 + SO_4^=$	4.0×10^{-13}	0
$RO_2 + SO_2 \rightarrow RO + SO_4^=$	2.0×10^{-15}	0
$RCO_3 + SO_2 \rightarrow RO_2 + SO_4^= + CO_2$	1.0×10^{-15}	0
Organic radical reactions		
$RCO_3 + RCO_3 \rightarrow HC_4 + CO_2$	1.0×10^{-12}	0
$RO_2 + NO \rightarrow RO + NO_2$	4.0×10^{-12}	-300
$RCO_3 + NO \rightarrow RO_2 + NO_2 + CO_2$	3.0×10^{-12}	-300
$RCO_3 + NO_2 \rightarrow PAN$	2.7×10^{-13}	0
$RO + O_2 \rightarrow HO_2 + HC_4$	1.0×10^{-12}	-2200
$RO + NO_2 \rightarrow RNO_3$	2.0×10^{-12}	0
$RO + NO \rightarrow RNO_2$	2.0×10^{-12}	0
$RO_2 + HO_2 \rightarrow ROOH + O_2$	2.7×10^{-12}	0
$RO_2 + RO_2 \rightarrow RO + RO + O_2$	2.7×10^{-13}	0

[a] A and C defined by $k = A \exp(C/T)$, where T is temperature in K.

[b] All photolysis rates are calculated as a function of solar zenith angle.

VERIFICATION

The revised model chemistry, when used with the 1973 emissions inventory developed as part of the original LIRAQ project, causes calculated ozone concentrations to increase by about 5-15% (less in downwind areas, more near the source regions) and to peak earlier by ~ 1/2 hr to 1 hr. A similar decrease in calculated NO concentrations was obtained. All other pollutants were affected to a lesser extent by the revision in model chemistry.

EMISSION INVENTORIES - GENERAL CONSIDERATIONS

Of more consequence were several changes made in the generation of the emissions inventory. Table 2 gives a summary of the emissions inventories prepared by the Bay Area Air Pollution Control District for 1973 as part of the LIRAQ project, and the emissions inventories for 1975 and 1985 prepared by the BAAPCD, the Metropolitan Transportation Commission (MTC) and the Association of Bay Area Governments (ABAG) as part of the preparation of the AQMP. These emissions inventories were prepared using a modified treatment of motor vehicle emissions. This is the primary cause of the factor of two difference in CO emissions between the 1973 and 1975 inventories. In addition, the methodology for assigning hydrocarbon emissions to the three reactivity classes used in LIRAQ-2 was modified in response to recently developed data. Also, the method for distributing "population distributed" sources over the grid was modified to reflect the distribution of employment. Largely as a result of the change in the methodology for assigning hydrocarbons to reactivity classes, the mean reactivity of the emissions was reduced by about 30%. When the 1975 inventory is used, LIRAQ-2 predicts less ozone in downwind areas like Livermore, but more ozone in source regions like San Jose than when the 1973 inventory is used.

Table 2 - Total in BAAPCD Inventory (tons/day)

Year	THC	HC_1	HC_2	HC_4	NO_x	CO	SO_2	Part
1973	985	309	654	13.0	782	2270	2880	152
1975	1011	217	742	51.5	693	4278	230	169
1985	782	166	580	36.2	725	3967	484	192

Although the methodology used in preparing the 1975 emissions inventory probably results in a better assignment of hydrocarbon emissions from anthropogenic sources, it may not have produced a superior overall emissions inventory. Biogenic emissions of hydrocarbons are fairly poorly characterized, but a strong correlation between winter rains and summer oxidant exists in the San Francisco Bay Area, and suggests a possible role for terpenes or other biogenic hydrocarbons in forming oxidant in the San Francisco Bay Area.(12) Considerations of the amount of forest land in the Bay Area, and the estimated emissions of terpenes from conifer forests would also suggest the possibility that a substantial portion of reactive hydrocarbon emissions in the San Francisco Bay Area may be non-anthropogenic.(10,12)

Nonetheless, we have employed the 1975 emissions inventory in this study. Although this inventory does not include non-anthropogenic emissions, it does produce verification statistics similar to those obtained earlier and reported in MacCracken et al.(2,3) and Duewer et al.(5)

Because the results reported here report comparisons between model calculations, some types of error will tend to cancel. Errors of this type include potential errors in non-aircraft emissions, the representation of large scale transport, boundary and initial conditions, and some aspects of the model chemistry. Potential errors associated with aircraft emissions, the two-dimensional treatment used in the model, vertical profiles, major errors in model chemistry, treatment of subgrid scale mixing, etc. are much less likely to be largely removed by comparing control and perturbed model runs.

EMISSION PERTURBATION

In performing the study, we made baseline runs using the 1975 and 1985 emissions inventories developed as part of the air quality maintenance plan (12) and the July 26, 1973 meteorology. The meteorology was chosen because it represents the day in the LIRAQ library for which the model predicts the highest O_3 concentrations, and because it had the highest observed oxidant of the days for which detailed meteorological data are available.

In addition, we performed experiments using emissions inventories for both 1975 and 1985 with the aircraft emissions doubled and with aircraft emissions halved. The methods used in generating the aircraft emissions inventories are described by BAAPCD (13) and in less detail by ABAG (11). The inventories include only aircraft emissions (approach, taxi, idle, take off, and climb out), they include commercial, military, and general aviation. The aviation emissions are compared to emissions from other activities in Table 3, and Table 4 gives a breakdown into emissions from the three major Bay Area commercial airports (San Francisco, San Jose, and Oakland), the military airports (Alameda Naval Air Station, Moffett Field, Travis AFB, and Hamilton AFB), and the several general aviation airports in the Bay Area. The model domain used omits Travis AFB and about half of the general aviation in the greater San Francisco Bay Area. Commercial aviation accounts for about 2/3 of the emissions in the inventories used.

RESULTS

Figures 1 to 27 give computed species concentrations and perturbations for several species and stations around the Bay Area when the 1975 emissions inventory and the perturbations based on it are used. As is evident, changes in aircraft emissions cause small changes in species concentrations except near the major airport areas where larger changes do occur. This is to be expected since aviation accounts for roughly 2-3% of area wide hydrocarbon and NO_x emissions, but accounts for more than 50% of emissions in some grid squares.

The computed perturbation in species concentration due to aircraft emissions is readily understood for the primary pollutants (i.e., when emissions are doubled, HC_1, HC_2, NO, and CO all display modest increases in concentration, with the increases largest near the major airports) and the behavior of NO_2 and aldehydes (HC_4), species that are largely derived from the oxidation of primary pollutants, closely parallels the behavior of the primary pollutants if one allows for the time it takes to produce them from the primary pollutants.

The pollutant of primary concern in the Bay Area, ozone, is affected in a more complex manner. A small increase in hydrocarbon emissions tends to lead to more ozone and a more rapid generation of oxidants. An increase in NO_x emissions tends to slow the rate of ozone production, reduce the peak O_3 concentrations reached, at least in areas near the NO_x source, and at least qualitatively, to

Table 3 - Baseline Emission Totals

Oxides of Nitrogen as Nitrogen Dioxide, Tons/Day

Source of Emissions	1975	1985
Point (PNT)	192.16	295.92
Area (POP)	101.02	161.05
Airports (AIR)	13.20	19.20
Stationary Total	306.38	476.17
Mobile (CAR)	390.09	249.05
GRAND TOTAL (QSOR)	696.47	725.22

Alkenes, Tons/Day

Source of Emissions	1975	1985
Point (PNT)	25.92	29.11
Area (POP)	80.68	83.45
Airports (AIR)	7.07	7.10
Stationary Total	113.67	119.66
Mobile (CAR)	103.60	46.54
GRAND TOTAL (QSOR)	217.27	165.20

Alkanes, Tons/Day

Source of Emissions	1975	1985
Point (PNT)	98.16	107.98
Area (POP)	299.30	309.50
Airports (AIR)	12.60	12.66
Stationary Total	408.06	430.14
Mobile (CAR)	333.90	150.04
GRAND TOTAL (QSOR)	741.96	580.18

Aldehydes, Tons/Day

Source of Emissions	1975	1985
Point (PNT)	4.63	5.20
Area (POP)	14.41	14.90
Airports (AIR)	2.85	2.86
Stationary Total	21.89	22.96
Mobile (CAR)	29.61	13.22
GRAND TOTAL (QSOR)	51.50	36.18
GRAND TOTAL ALL ORGANICS (QSOR)	1,010.50	782.20

Oxides of Sulfur as Sulfur Dioxide, Tons/Day

Source of Emissions	1975	1985
Point (PNT)	197.67	424.73
Area (POP)	12.25	32.86
Airports (AIR)	1.28	1.51
Stationary Total	211.20	459.10
Mobile (CAR)	18.89	24.80
GRAND TOTAL (QSOR)	230.09	483.90

Carbon Monoxide, Tons/Day

Source of Emissions	1975	1985
Point (PNT)	80.40	82.91
Area (POP)	336.20	288.30
Airports (AIR)	54.14	67.97
Stationary Total	470.74	539.18
Mobile (CAR)	3,808.00	3,428.00
GRAND TOTAL (QSOR)	4,278.74	3,967.18

Table 4 - Central Bay Area* Aircraft Emissions

1975	HC	NO_x	CC
Commercial	10.69	8.87	26.01
Military	3.03	1.67	4.74
General	2.39	.77	11.86
TOTAL in LIRAQ-2 Domain	16.11	11.31	42.61
TOTAL IN BAAPCD INVENTORY	19.60	13.30	54.40
1985			
Commercial	8.57	13.69	31.72
Military	1.91	1.46	2.02
General	4.61	1.44	20.75
TOTAL in LIRAQ-2 domain	15.09	16.59	54.49
TOTAL IN BAAPCD INVENTORY	20.20	19.60	69.90

*Does not include Travis AFB or general aviation emissions associated with extreme north, south, or eastern portions of the Bay Area.

oppose the effect of increased hydrocarbon emissions. We find that when the 1975 aircraft emissions are doubled, ozone concentrations are generally calculated to be lower than for the baseline before the ozone peak is reached. Later in the day, and at the peak hour, ozone concentrations are computed to be increased - by as much as 4 ppb. However at San Francisco Airport a reduction is computed. The ozone reductions in the early morning and at San Francisco Airport can be credited to the inhibitory effect of increases in NO_x emissions. The later increases reflect an increase in the potential for ozone production caused by increased hydrocarbon emissions. Although the computed ozone perturbations are small compared to the standard, they are not negligible. Many days on which the ozone standard is violated are days for which the violation is by 1 pphm (10 ppb), the smallest unit routinely recorded. It is quite plausible that roughly 10% of those days would cease to be violations if ozone were reduced by 1 ppb, and that the number of marginal violations might be increased by slightly more than 10% if ozone concentrations increased by 1 ppb.

A significant observation was that the projected effects of halving aircraft emissions were quite close to -0.5 times the effects of doubling them. That is, the perturbations were linear in the multiplier applied to airport emissions. This was true for all the calculations made in this study except for a few very small perturbations (in this case, discrepancies were generally within the numerical uncertainty of our solution technique).

Computed concentrations and perturbations for calculations made using the 1985 emissions inventory are given in Figs. 28 to 54. The perturbations in primary pollutants, NO_2, and aldehydes are quite similar to those calculated using the 1975 emissions inventory. The only major difference being that changes in NO_x are about fifty percent larger than they were for the 1975 emissions inventory, this largely reflecting projected changes in aircraft engine type.

However, the projected effect of aircraft emissions on ozone is quite different in 1985 than in 1975. For the calculation made based on the 1935 emissions inventory, increasing aircraft emissions results in an ozone reduction over most of the model domain. Near the San Francisco Airport, the peak hour ozone reductions for doubled aircraft emissions exceed 10 ppb, and ozone reductions of 5 ppb or more were calculated for much of the Santa Clara Valley and San Francisco Peninsula. Significant ozone increases were calculated only at a few downwind stations, mostly in the northeastern part of the model domain.

This somewhat surprising result reflects two changes in the emissions inventories. First, the ratio of hydrocarbon emissions to NO_x emissions declined from 1.42 in the 1975 inventory to 0.90 in the 1985 inventories for the aircraft emissions inventory used in these calculations. Second, the ratio of hydrocarbons to NO_x in the general inventory declined from 1.45 to 1.07. The first change resulted in an increased inhibition of ozone production from NO_x directly while the change in over all emissions increased the sensitivity of ozone formation to NO_x in the model.

SUMMARY AND CONCLUSIONS

For calculations made with the 1975 emissions inventory, airport emissions lead to locally significant changes in primary pollutants, aldehydes and nitrogen dioxide, reduce ozone concentrations at San Francisco Airport, but lead to increases of up to 3 ppb in peak hour ozone slightly downwind of the major airports.

Calculations made with the projected 1985 emissions inventories suggest that primary pollutants are again increased by amounts that are significant near the major airports, but ozone concentrations are calculated to be reduced by aircraft emissions over most of the domain. This reduction in ozone reflects inhibition of ozone formation by nitric oxide emissions.

The behavior of the model near source regions is that which would be expected based on smog chamber results, and is likely to be at least qualitatively correct. The behavior of the model further downwind, especially when the 1985 emissions inventory was used, is less directly related to chamber experiments, and is more dependent on the accuracy of the detailed treatment of the chemistry, heterogeneous removal processes (which the model treats via simple deposition velocities), details of the projected emissions, etc. The validity of the results for the 1985 simulations is critically dependent on the validity of the projected NO_x/HC ratio in both the aircraft emissions and the projected general emissions inventory.

ACKNOWLEDGMENTS

We wish to thank L. Robinson, M. Kim and G. Paley of the BAAPCD for preparing the emissions inventory tapes and providing them to us. We also wish to thank A. J. Broderick and N. Sundararaman of HAPP. Without their strong encouragement, this work would never have been performed.

This work was performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore Laboratory under contract no. W-7405-Eng-48, and supported in part by the High Altitude Pollution Program of the Department of Transportation, Federal Aviation Administration.

REFERENCES

1. M. C. MacCracken, "User's Guide to the LIRAQ Model: An Air Pollution Model for the San Francisco Bay Area," Lawrence Livermore Laboratory Report UCRL-51983, 1975.

2. M. C. MacCracken and G. D. Sauter, eds., "Development of an Air Pollution Model for the San Francisco Bay Area," Final Report, Lawrence Livermore Laboratory Report UCRL-51920, Vol. 1, 1975.

3. M. C. MacCracken and G. D. Sauter, eds., "Development of an Air Pollution Model for the San Francisco Bay Area," Final Report, Lawrence Livermore Laboratory Report UCRL-51920, Vol. 2, appendices, 1975.

4. M. C. MacCracken, D. J. Wuebbles, J. J. Walton, W. H. Duewer and K. E. Grant, "The Livermore Regional Air Quality Model: 1. Concept and Development," J. Appl. Meteor., 17(3), March 1978, pp. 254-272.

5. W. H. Duewer, M. C. MacCracken and J. J. Walton, "The Livermore Regional Air Quality Model: II. Verification and Sample Application in the San Francisco Bay Area," J. Appl. Meteor., 17(3), March 1978, pp. 273-311.

6. G. D. Sauter, "A Workshop on the Livermore Regional Air Quality (LIRAQ) Model," Lawrence Livermore Laboratory, private communication, 1978.

7. A. Bass, A. Q. Eschenroeder and B. A. Egan, "The Livermore Regional Air Quality Model (LIRAQ): A Technical Review and Market Analysis," Environmental Research and Technology, Inc., Document P-2348-1, report to the NSF, 1977.

8. Systems Applications, Inc., "A Discussion of the Livermore Regional Air Quality Model and the SAI Urban Airshed Model," prepared by Systems Applications, Inc., San Rafael, Report ES, 1977.

9. J. Boris and D. L. Book, "Flux-Corrected Transport. I. SHASTA, a Fluid Transport Algorithm That Works," J. Comput. Phys., 11, 38, 1973.

10. W. H. Duewer, J. J. Walton, K. E. Grant and H. Walker, "Livermore Regional Air Quality (LIRAQ) Application to St. Louis, Missouri," Lawrence Livermore Laboratory Report UCRL-52432, 1978.

11. J. S. Sandberg, M. J. Basso and B. A. Okin, "Winter Rain and Summer Ozone: A Predictive Relationship," Science, 200, 1978, pp. 1051-1054.

12. Association of Bay Area Governments, "Draft Environmental Management Plan," ABAG 1978. See also AQMP Technical Memo 17 by L. Robinson in the supporting documentation.

13. BAAPCD, "Aviation Effect on Air Quality in the Bay Region," ABAG, February 1971.

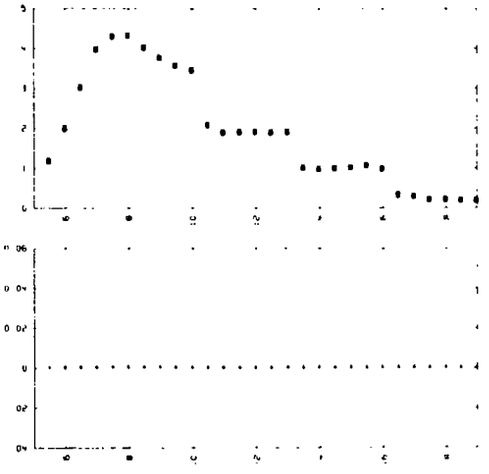


Fig. 1 - Computed surface concentrations of alkenes (ppmv) at the San Francisco monitoring station versus time. Top: O = 1975 baseline run; X = 1975 inventory, with 2 times aircraft emissions. Bottom: Difference between perturbation and baseline (ppmv). The San Francisco station is in an urban area generally up wind of aircraft emissions. Alkenes are representative of all primary hydrocarbons

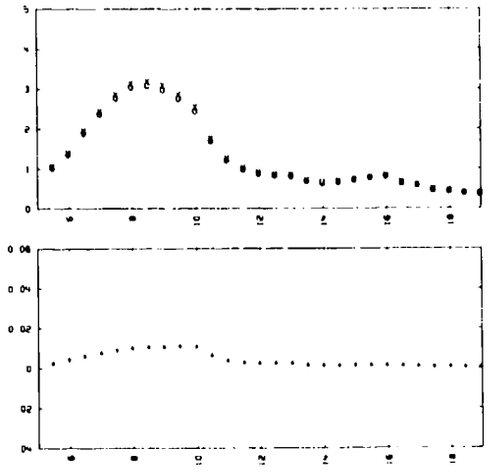


Fig. 2 - Same as Fig. 1, except at the San Jose monitoring station. The San Jose station is down wind of several major airports and is one of the more severely polluted areas in the Bay Area

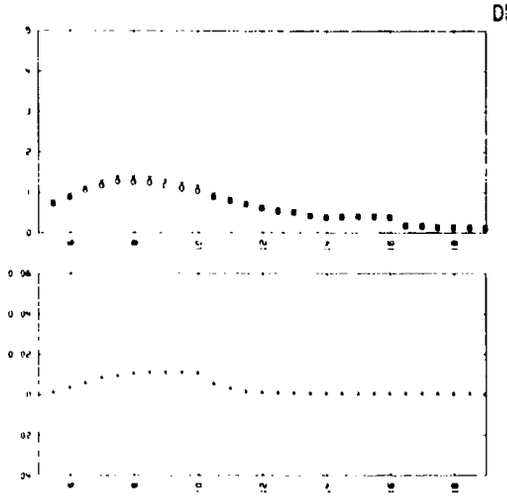


Fig. 3 - Same as Fig. 1, except at the Burlingame air monitoring station. The Burlingame station is less than 5 km down wind of San Francisco airport

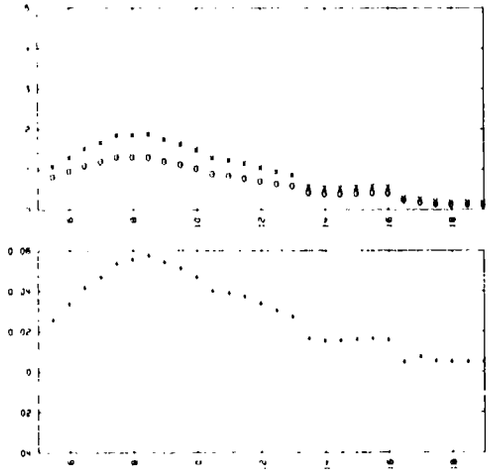


Fig. 4 - Same as Fig. 1, except at San Francisco International Airport. This airport accounts for roughly half of all aircraft emissions in the model domain

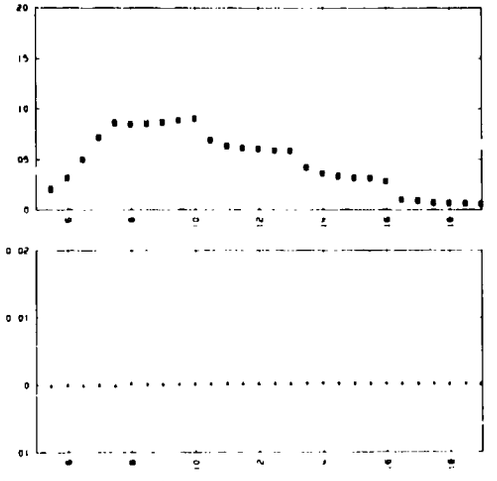


Fig. 5 - Same as Fig. 1, except aldehyde concentrations are given

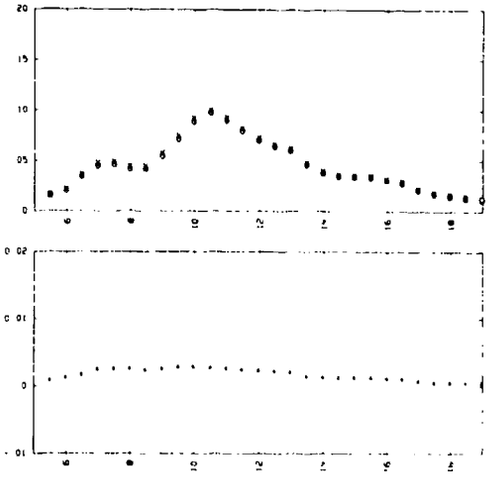


Fig. 6 - Same as Fig. 2, except aldehyde concentrations

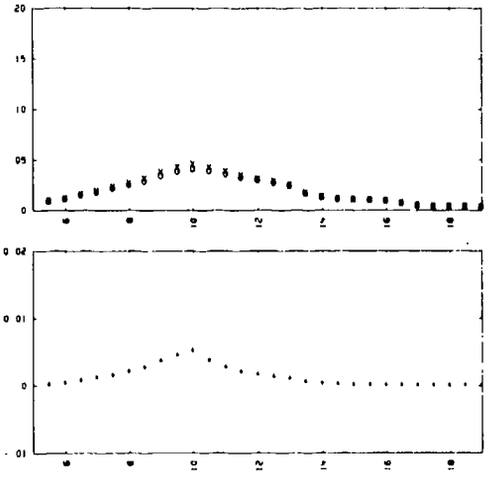


Fig. 7 - Same as Fig. 3, except aldehyde concentrations

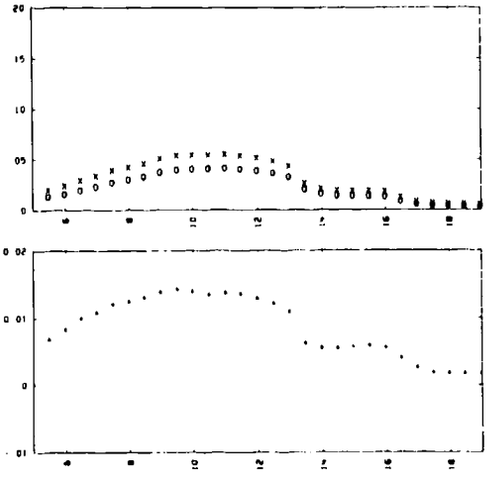


Fig. 8 - Same as Fig. 4, except aldehyde concentrations

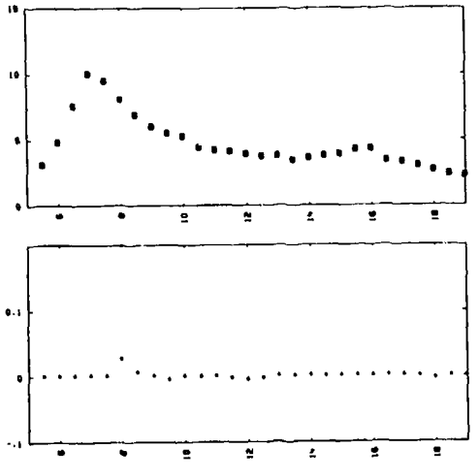


Fig. 9 - Same as Fig. 1, except carbon monoxide

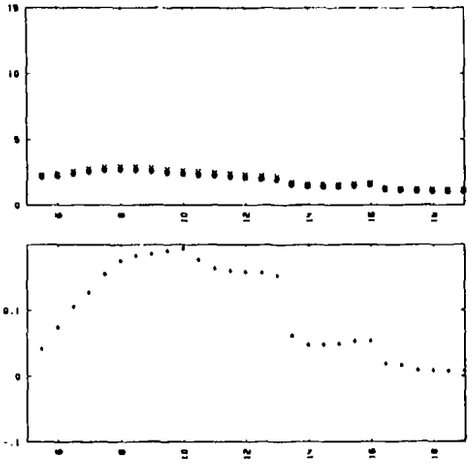


Fig. 12 - Same as Fig. 4, except carbon monoxide

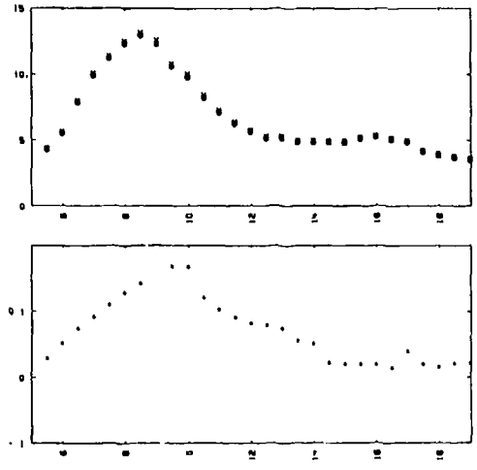


Fig. 10 - Same as Fig. 2, except carbon monoxide

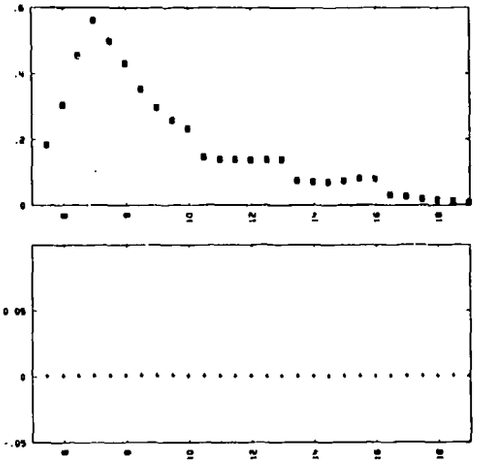


Fig. 13 - Same as Fig. 1, except nitric oxide

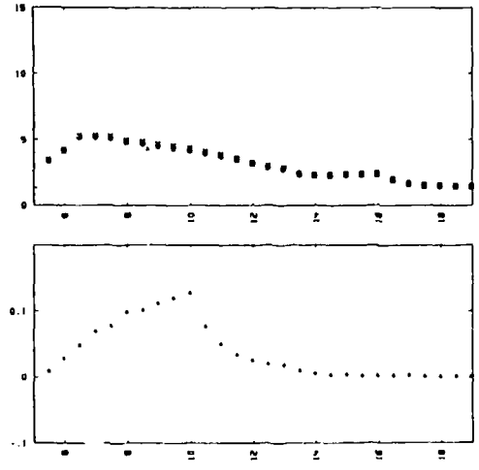


Fig. 11 - Same as Fig. 3, except carbon monoxide

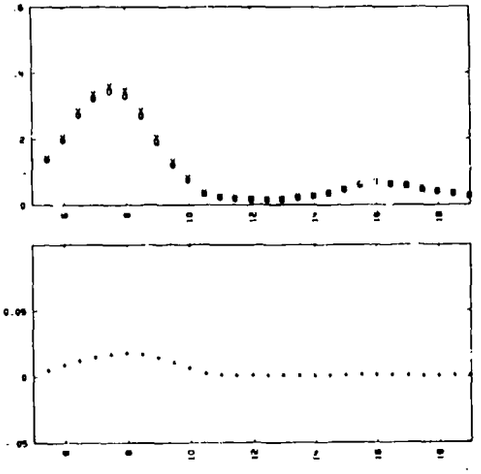


Fig. 14 - Same as Fig. 2, except nitric oxide

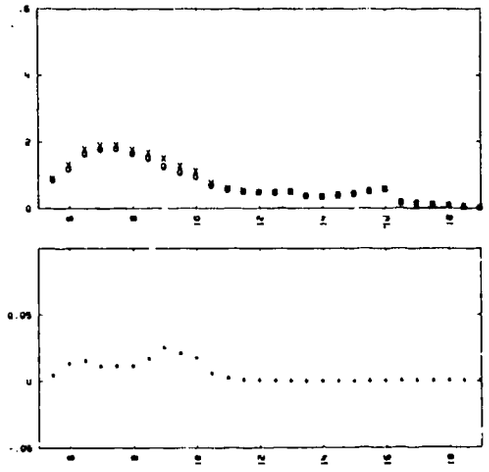


Fig. 15 - Same as Fig. 3, except nitric oxide

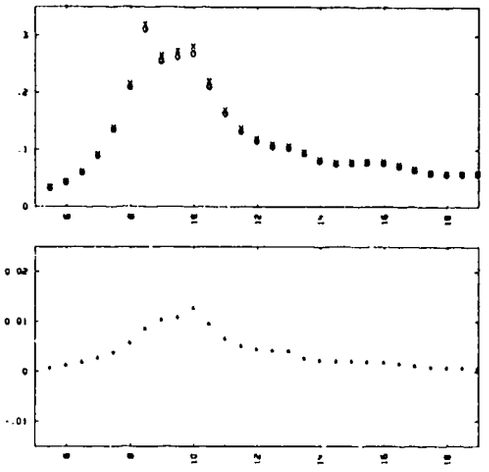


Fig. 18 - Same as Fig. 2, except nitrogen dioxide

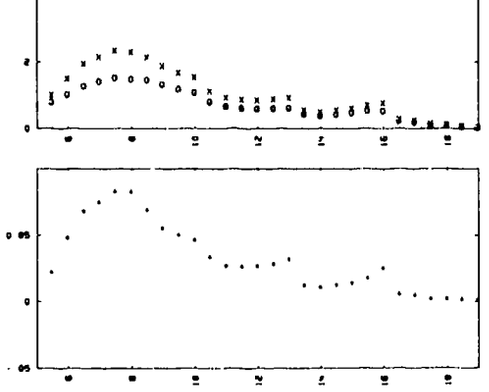


Fig. 16 - Same as Fig. 4, except nitric oxide

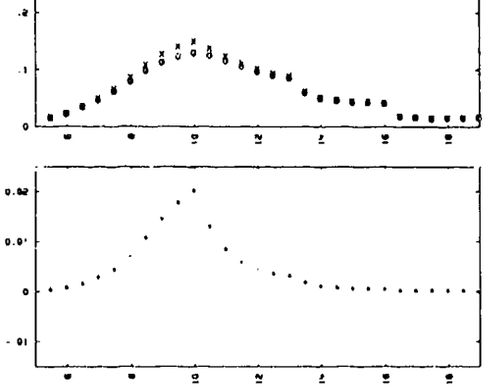


Fig. 19 - Same as Fig. 3, except nitroyen dioxide

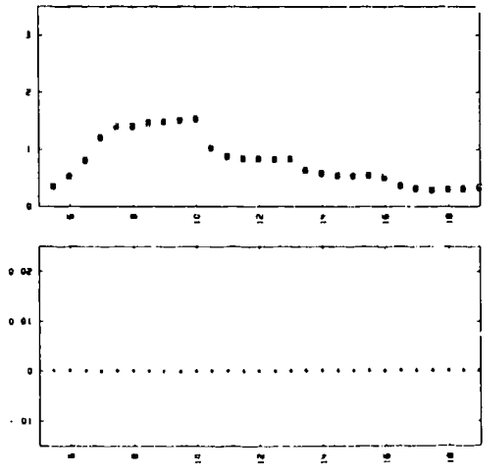


Fig. 17 - Same as Fig. 1, except nitrogen dioxide

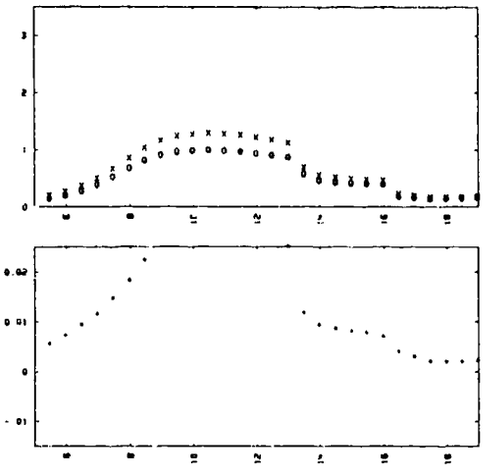


Fig. 20 - Same as Fig. 4, except nitrogen dioxide

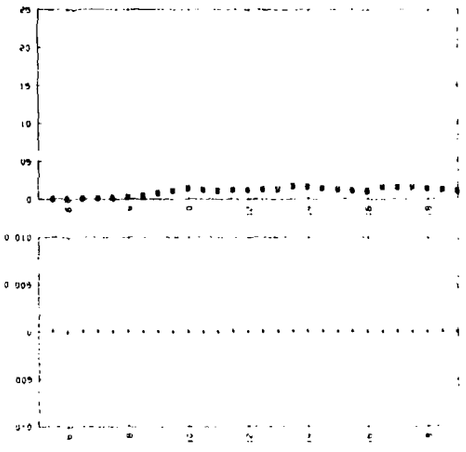


Fig. 21 - Same as Fig 1, except ozone

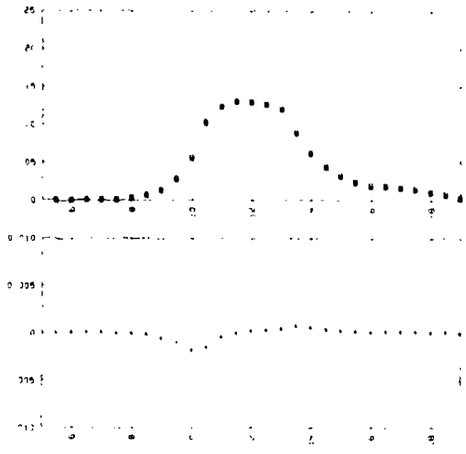


Fig. 22 - Same as Fig. 2, except ozone

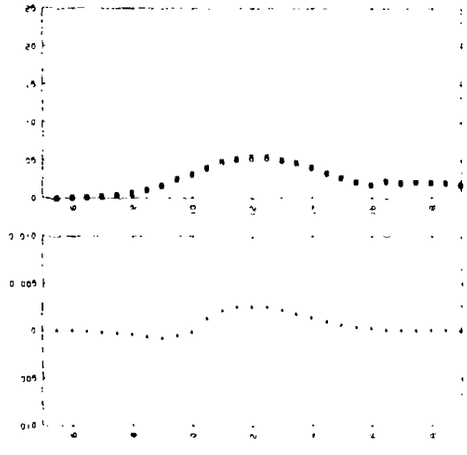


Fig. 23 - Same as Fig. 3, except ozone

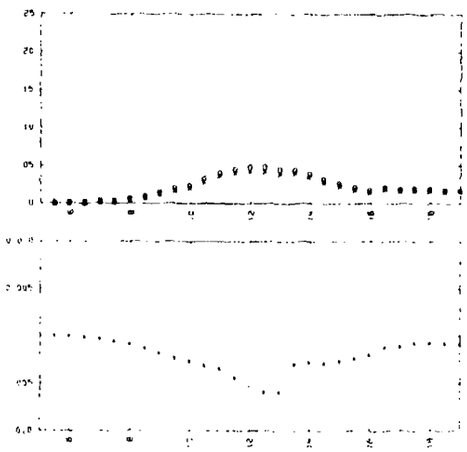


Fig. 24 - Same as Fig. 4, except ozone

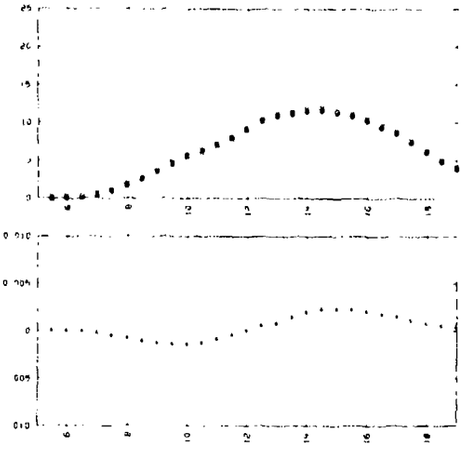


Fig. 25 - Same as Fig. 24, except at Livermore, a station down wind of the major urban centers and airports with a large local general aviation airport

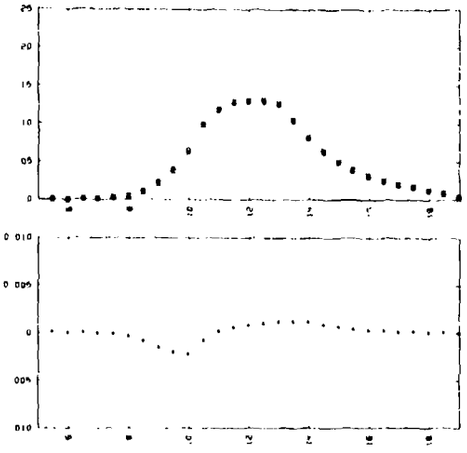


Fig. 26 - Same as Fig. 24, except at San Jose Municipal Airport, second largest commercial airport in the Bay Area

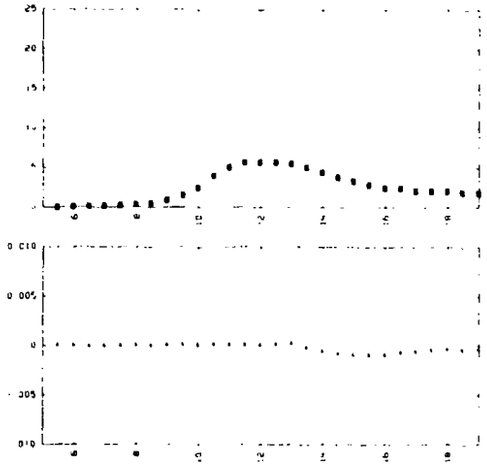


Fig. 27 - Same as Fig. 24, except at Oakland Airport, third largest airport in the Bay Area

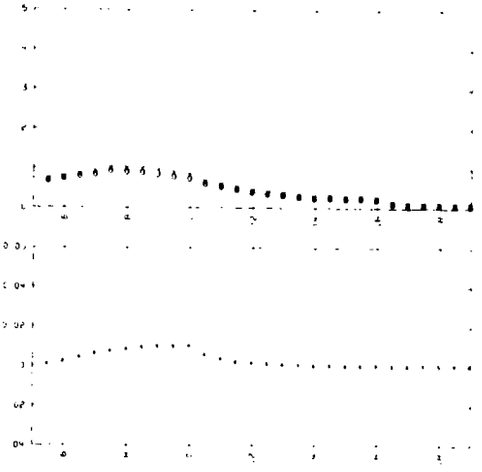


Fig. 30 - Same as Fig. 3, except 1985 inventories

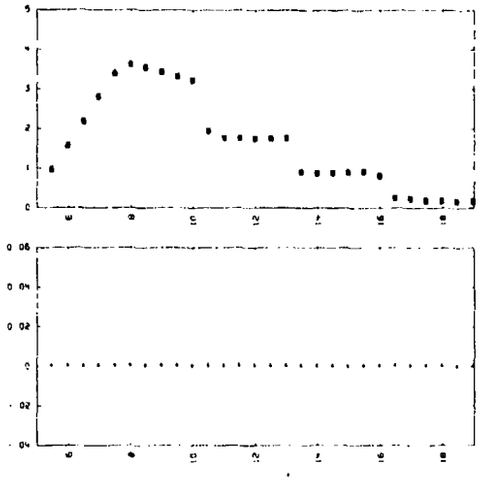


Fig. 28 - Same as Fig. 1 except 1985 inventories

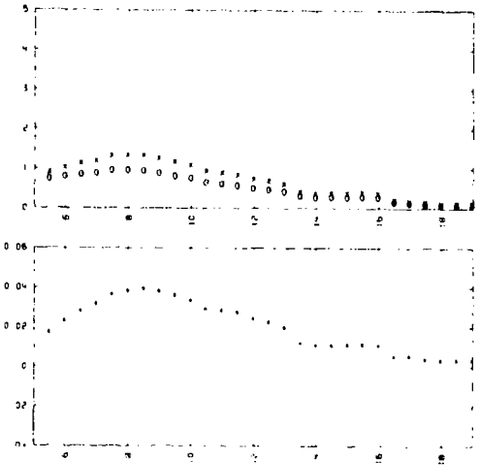


Fig. 31 - Same as Fig. 4 except 1985 inventories

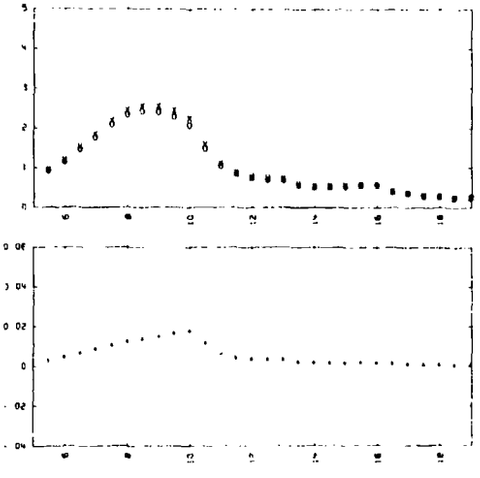


Fig. 29 - Same as Fig. 2, except 1985 inventories

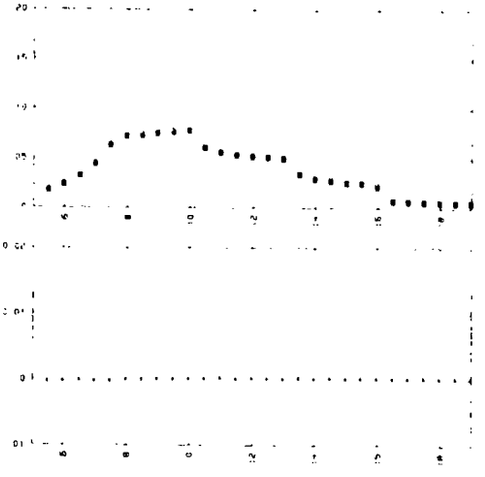


Fig. 32 - Same as Fig. 5, except 1985 inventories

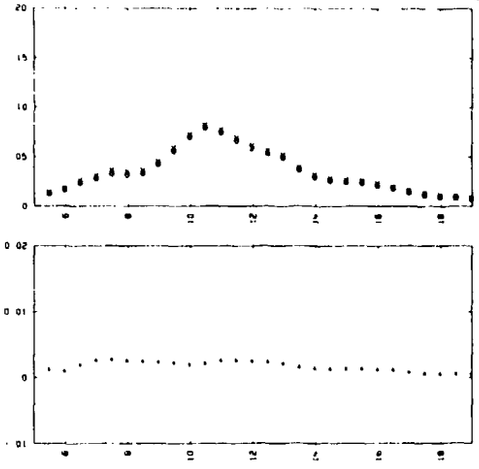


Fig. 33 - Same as Fig. 6, except 1985 inventories

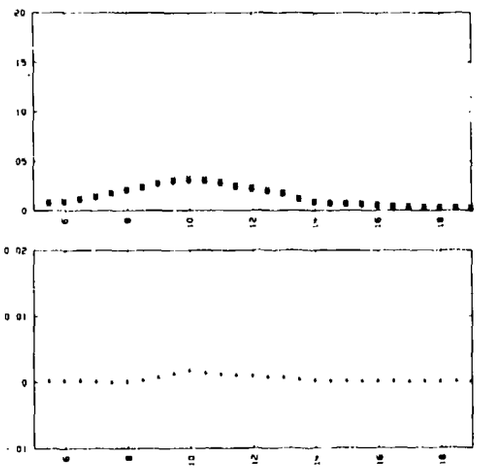


Fig. 34 - Same as Fig. 7, except 1985 inventories

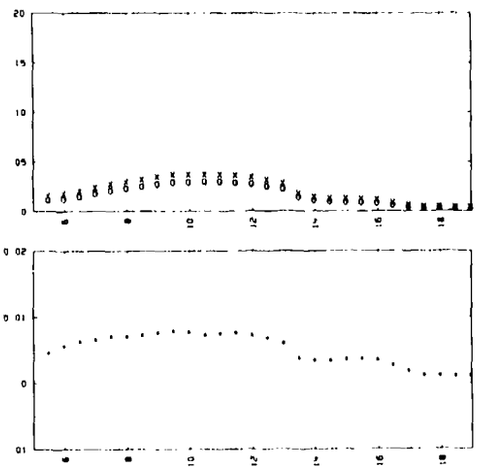


Fig. 35 - Same as Fig. 8, except 1985 inventories

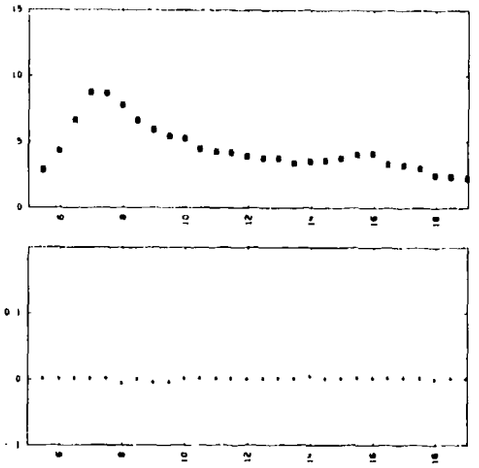


Fig. 36 - Same as Fig. 9, except 1985 inventories

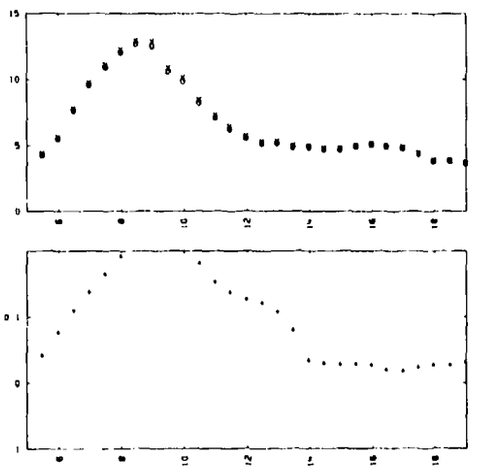


Fig 37 - Same as Fig. 10, except 1985 inventories

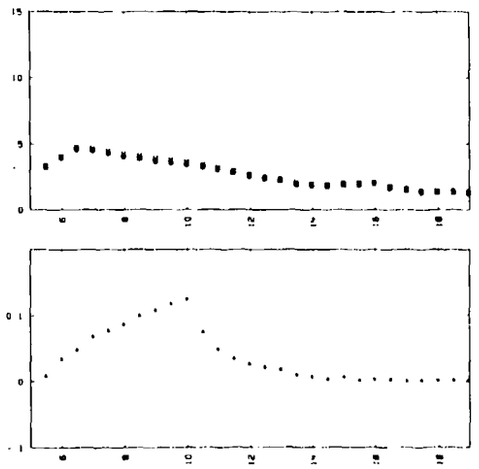


Fig. 38 - Same as Fig. 11, except 1985 inventories

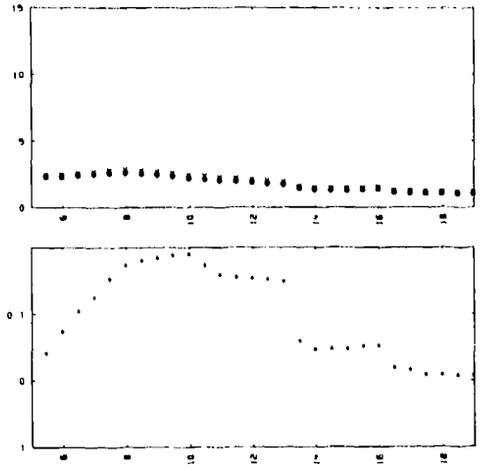


Fig. 39 - Same as Fig. 12, except 1985 inventories

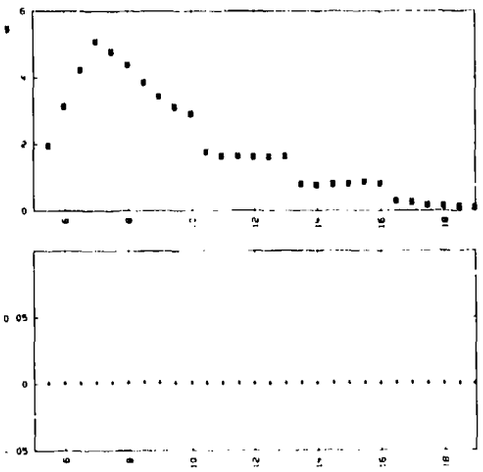


Fig. 40 - Same as Fig. 13, except 1985 inventories

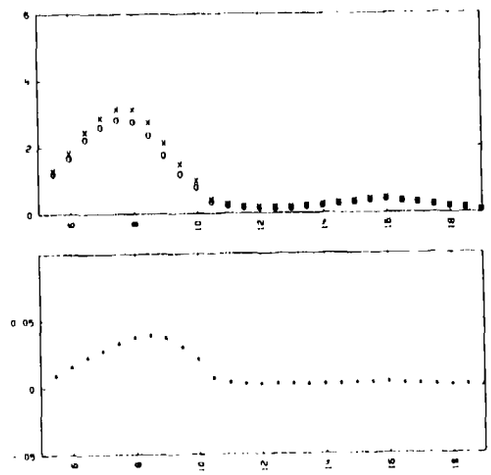


Fig. 41 - Same as Fig. 14, except 1985 inventories

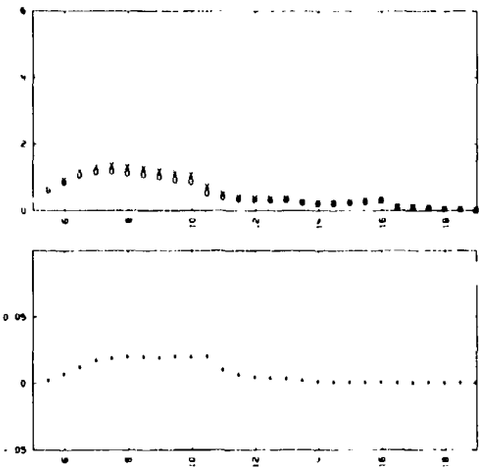


Fig. 42 - Same as Fig. 15, except 1985 inventories

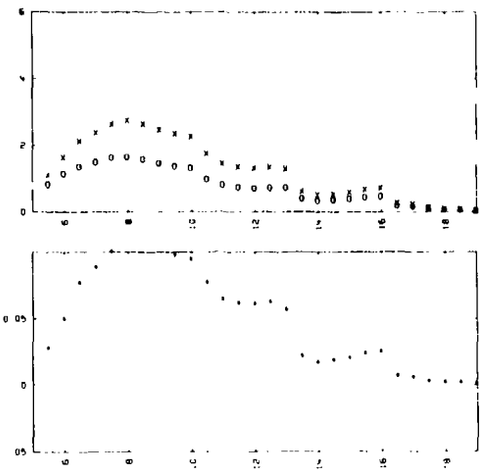


Fig. 43 - Same as Fig. 16, except 1985 inventories

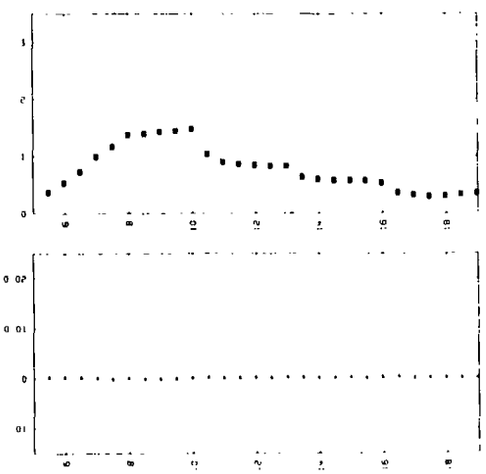


Fig. 44 - Same as Fig. 17, except 1985 inventories

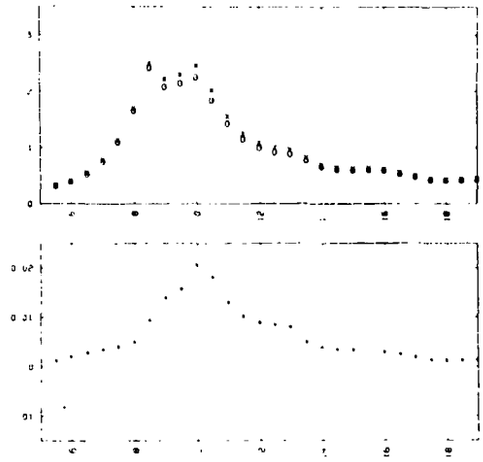


Fig. 45 - Same as Fig. 18, except 1985 inventories

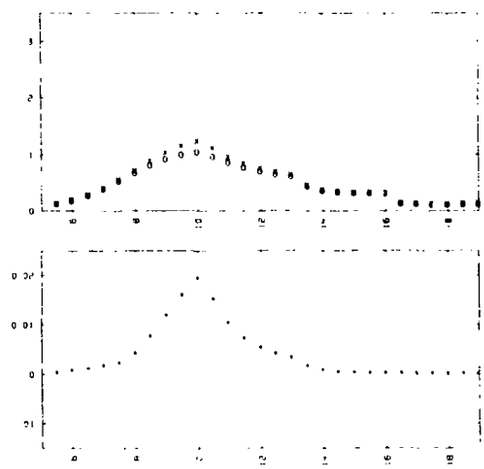


Fig. 46 - Same as Fig. 19, except 1985 inventories

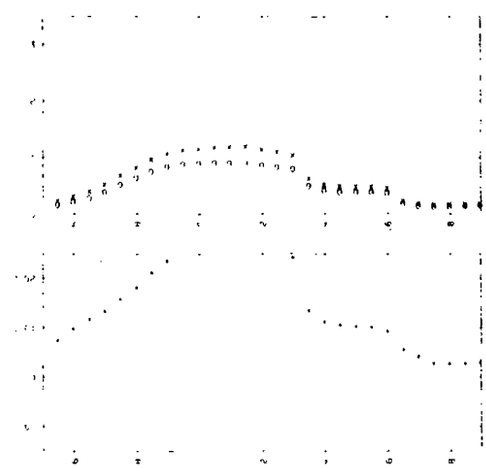


Fig. 47 - Same as Fig. 20, except 1985 inventories

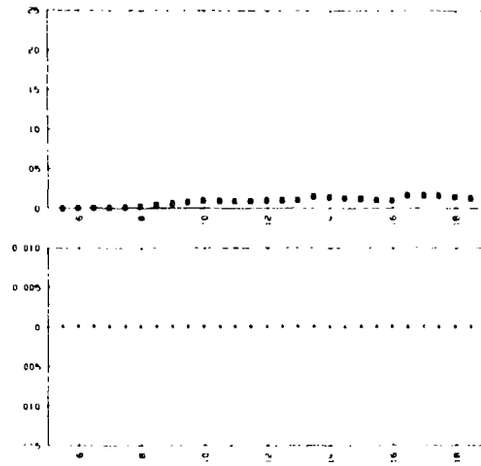


Fig. 48 - Same as Fig. 21, except 1985 inventories

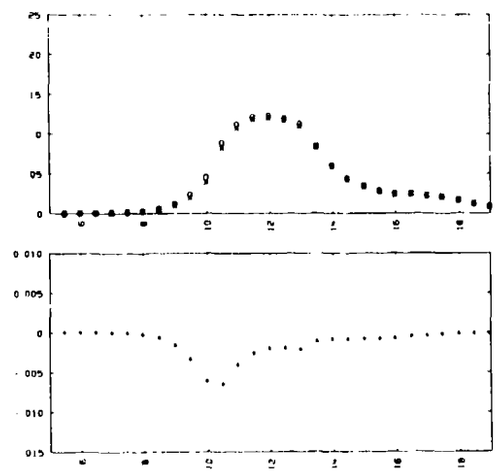


Fig. 49 - Same as Fig. 22, except 1985 inventories

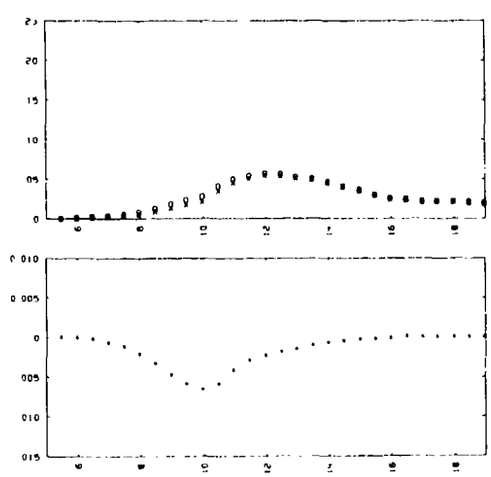


Fig. 50 - Same as Fig. 23, except 1985 inventories

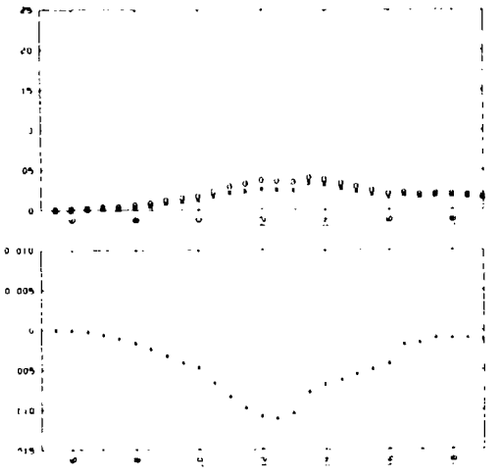


Fig. 51 - Same as Fig. 24, except 1985 inventories

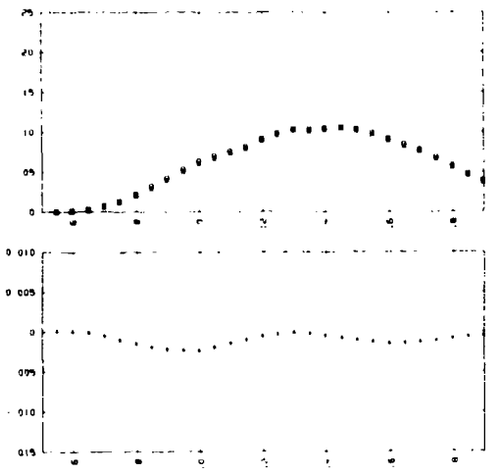


Fig. 52 - Same as Fig. 25, except 1985 inventories

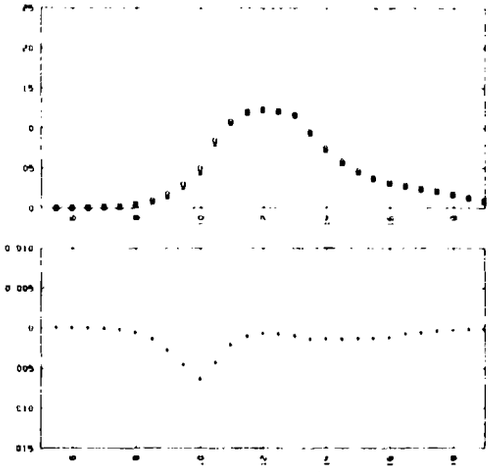


Fig. 53 - Same as Fig. 26, except 1985 inventories

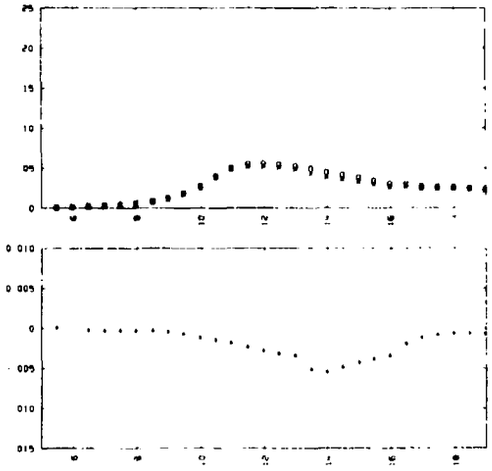


Fig. 54 - Same as Fig. 27, except 1985 inventories

DISCUSSION

HUIE: Did you look at the equivalent effect on other things besides ozone, for example, nitrates, PAN?

DUEWER: We do not calculate nitrates at all. We do calculate a nitric acid, which is a lumping of the nitrates.

Also while we have PAN form, we don't really carry PAN in the mechanism, so yes, there would be an increase in PAN as well, and, of course, there is a question as to whether the oxidant standard is now an ozone standard, but the data that justified the oxidant standard were oxidant data. The data dealt with measurements of oxidant, not ozone, which includes a number of things other than ozone, and the real health effects may not be related to ozone in any very direct way at all.

Ozone is a kind of surrogate, and it is quite possible that the health effects would be more reflective of PANs and other compounds, including nitrogen.

TESCHE: Could you comment on the spatial relation and how the aircraft emissions were treated in the inventory?

DUEWER: We use a two-dimensional model, five kilometer by five kilometer grid, and, as I said, the aircraft emissions were treated as surface sources.

POLLUTION BY AIRCRAFT TRAFFIC
POLLUTION PREVISION MODEL IN THE VICINITY OF AIRPORTS
APPLICATION TO VARIOUS AIRPORTS : ORLY AND ROISSY-EN-FRANCE

Jean Delsey - Robert Joumard - Gérard Péri (+)

Institut de Recherche des Transports
Centre d'Evaluation et de Recherche des Nuisances
69672, Bron Cedex, FRANCE

ABSTRACT

The differential equation of pollutant turbulent diffusion is numerically resolved, after some simplifications, for airports. The hypotheses which led to wind and diffusivities formulas are indicated. Data are given for calculating the different parameters, particularly those of aircraft pollutant emissions depending on different types of aircraft. The model is operational for any airport and shows the importance of meteorological factors.

SINCE THE LAST DECADE, numerous numerical models of pollutant spreading in the atmosphere have been developed. Most of them regard essentially either an urban agglomération or a highway. But, to our knowledge, few authors were interested by the modelization of emitting sources of an airport and of spreading, except (1) (++) of whom the theoretical approach is different enough. As for us, this topic was dealt with more widely in a report published in 1975 (2).

BASIC EQUATION

The problem of the "a priori" determination of a pollution level in an area D arbitrarily limited by a contour Γ may be summarized in the following formula : solve in any point (x, y, z) of that area and at any time t the equation

$$\frac{\partial C}{\partial t} + \frac{\partial C u_i}{\partial x_i} = \frac{\partial}{\partial x_j}\left(\rho \mathcal{D} \cdot \frac{\partial C}{\partial x_j}\right) + Q(X_i, t) - A(X_i, t) \qquad (1)$$

in consideration of a number of conditions at limits on the contour and knowing the distribution functions of emitting sources (Q) and of absorption (A) of pollutant.

Now, for solving equation (1), it is necessary to solve the system of the 6 equations with partial derived.

The variables U_i and C are in the atmospheric limit layer time and space aleatory variables ; one splits them in a mean value ($\tilde{U}_i$, $\tilde{C}$) and a turbulent fluctuation (u_i, c) of zero mean.

$$U_i = \tilde{U}_i + u_i \quad \text{with} \quad u_i = 0$$

it is then deduced :

$$\frac{\partial \tilde{C}}{\partial t} + \frac{\partial}{\partial x_i}(\tilde{U}_i \tilde{C}) + \frac{\partial}{\partial x_i}\widetilde{u_i c} = \frac{\partial}{\partial x_j}\left(\widetilde{\rho \mathcal{D} \frac{\partial C}{\partial x_j}}\right) + \tilde{Q} - \tilde{A} \qquad (2)$$

if we put down : $\rho = \rho_0 + \rho_1$; $P = P_0 + P_1$; $P_1 = \tilde{P}_1 + p$; $T = T_0 + T_1$; $T_1 = \tilde{T}_1 + \theta$

ρ_0, P_0 and T_0 being the equilibrium values and ρ_1, P_1 and T_1 being the instantaneous variations of corresponding magnitudes. It is then obtained for the 6 equations with partial derived :

- the mass balance :

$$\frac{\partial \tilde{U}_i}{\partial x_i} = 0 \qquad (3)$$

- the balance of amount of movement :

$$\frac{\partial \tilde{U}_i}{\partial t} + \tilde{U}_j \cdot \frac{\partial \tilde{U}_i}{\partial x_j} = -\frac{1}{\rho_0} \cdot \frac{\partial \tilde{P}_1}{\partial x_i} + \nu \frac{\partial^2 \tilde{U}_i}{\partial x_j^2} - \frac{\partial}{\partial x_j}\widetilde{u_i u_j} + \frac{g}{T_0} T_1 \delta_{3i} + F_{ci}$$

for $i = 1, 2, 3$ (4)

- the power balance :

$$\frac{\partial T_1}{\partial t} + \tilde{U}_i \frac{\partial T_1}{\partial x_i} = \alpha \cdot \frac{\partial^2 T_1}{\partial x_i^2} - \frac{\partial}{\partial x_i}\widetilde{\theta u_i} + \frac{1}{\rho_0 C_p} \cdot \frac{\partial \tilde{Q}_i}{\partial x_i} \qquad (5)$$

- the state equation :

$$\tilde{\rho}_1 = -\frac{\rho_0}{T_0} \cdot \tilde{T}_1$$

Let us note that the symbol (~) represents a statistical mean in opposition to the symbol (-) which represents a temporal mean.

It is necessary to make a number of hypotheses in order to simplify the solving of the problem :

HYPOTHESIS 1 : if the model resolution period is equal or lower than an hour, the variables U_i, ρ, P and T may be considered as statistically stationary (3, 4). In these conditions, the statistical mean will be replaced by the temporal mean.

+ now in Société Comex, 13000, Marseille, France
++ Numbers in parentheses designate References at end of paper

HYPOTHESIS 2 : the air volume mass has a distribution which is neighbouring its equilibrium distribution ρ_0.

HYPOTHESIS 3 : account taken of the scale of the area (10 x 10 x 1 km) and of the fact the ground is little or not uneven, the flow is considered as homogenous in a horizontal plane.

HYPOTHESIS 4 : $\bar{A}(x_i, t) = 0$

HYPOTHESIS 5 : we replace the intermittent sources by stationary continuous sources.

The statistical means of equation (2) will be replaced by temporal means.

HYPOTHESIS 6 : the turbulent diffusitivities K_x, K_y, K_z defined as follows are introduced :

$$u_i c = - K_x \cdot \frac{\partial c}{\partial x} \qquad (7)$$

$$u_i c = - K_y \cdot \frac{\partial c}{\partial y} \qquad (8)$$

$$u_j c = - K_j \cdot \frac{\partial c}{\partial j} \qquad (9)$$

The turbulent diffusitivities are flowing properties, and not of the fluid (as D).

On the other hand, except at immediate ground vicinity or at proximity of a temperature reversion layer, the molecular diffusion terms can be disregarded vis-à-vis the turbulent diffusion terms.

HYPOTHESIS 7 : the x axle being parallel to the wind direction, we classically neglect the term of longitudinal diffusion $\frac{\partial}{\partial x} K_x \frac{\partial \bar{c}}{\partial x}$ before the term of transport by the wind : $\bar{U} \cdot \frac{\partial c}{\partial x}$ though that approximation is no more valid in the vicinity of the source, especially as U is large.

HYPOTHESIS 8 : we shall assume that the wind direction is unvariable with altitude, which is almost exact in the surface layer.

Due to these simplifying hypotheses, we achieve a simplified diffusion equation :

$$\bar{U} \cdot \frac{\partial \bar{c}}{\partial x} = \frac{\partial}{\partial y} K_y \frac{\partial \bar{c}}{\partial y} + \frac{\partial}{\partial j} K_j \frac{\partial \bar{c}}{\partial j} \qquad (10)$$

with conditions to following limits :

$$K_z \frac{\partial c}{\partial j} = 0 \qquad \text{for } z = 0 \quad \text{or } z = H_I$$

which supposes that the mass flow is zero at ground level and at H_I level of the reversion layer.

$\iint \bar{U} \bar{c} \, dy \, dz = Q$ at level of a source point, Q being the mass output per time unit.

Finally, for solving equation (10), it is sufficient to take, a priori, a wind profile $\bar{U}(z)$ and the variation laws of coefficients K_y and K_z.

WIND PROFILE AND DIFFUSION COEFFICIENTS MODELING

It is known that the atmospheric limit layer may split into a surface layer in the first tens of meters and an external layer, often called Eckmann layer, where the effects of the Coriolis strength begin to be experienced.

Externally to the limit layer, the wind (geostrophic wind) follows the general laws of atmosphere.

HYPOTHESIS 9 : we shall assume that in the surface layer, where the wind and temperature profiles comply with ultimate similarity laws (Prandtl and Monin-Obukhov theories), the Reynolds analogy between vertical transfer of mass and that of movement quantity is rigorously respected, in other words that $\frac{Km}{Kz}$, Schmidt number of turbulence, is constant and equal to 1.

HYPOTHESIS 10 : at the outside of the surface layer, we shall assume K_z as constant and equal to its value at the border of the surface layer. In that which regards the wind profile of this layer, we shall use the relationships proposed by Ragland (5).

The thickness of the atmospheric limit layer is difficult to estimate. It is meanwhile an essential parameter in diffusion problems, for, in the absence of temperature reversion, that thickness defines the layer, called mixing layer, inside which pollutants will diffuse.

In presence of a temperature reversion, the height of the latter will be used as upper limit of the mixing layer (noted as H_I).

We shall use a formula proposed by Hanna (6), or :

$$z_{CL} = \frac{K \cdot u_*}{f}$$

with $u_* = \sqrt{\tau_0 / \rho}$ friction velocity, $f = 2\omega \sin \varphi$, Coriolis parameter, $K = 0{,}35$ Karman constant (7), z_{CL} being the height of the limit layer.

As to the thickness of the surface layer which is purely conventional, it varies with stability conditions. We shall use the same approximations as (5) with :

in neutral and unsteady cases : $z_{CS} = 0.1\ z_{CL}$

in steady cases : $z_{CS} = 6L$ for high stabilities $(6L \leqslant 0.1\ z_{CL})$

$z_{CS} = 0.1\ z_{CL}$ for low stabilities $(6L > 0.1\ z_{CL})$

L being the Monin-Obukhov length.

Account taken of hypotheses 9 and 10, K_j complies with a law of the form :

- in the surface layer : $(j \leqslant j_{cs})$, $K_j = \frac{K \cdot u_* \, j}{\phi_M}$

where ϕ is a function only depending upon $\frac{z}{L}$

Neutral stratification : $\phi_M = 1$

Unsteady stratification : $\phi_M = (1 - 15.\frac{z}{L})^{-0.25}$

Steady stratification : for $z \ll L$, $\phi_M = 1 + \beta \frac{z}{L}$ where β is a constant

for $z > L$, $\phi_M = 1 +$

- in the external layer : $(j_{cs} < j \leqslant j_{cL})$, $K_j = K_{j,cs}(j_{cs})$

With our hypothesis, we obtain for wind profiles in the surface layer :

- Neutral case : $\bar{U}(j) = \frac{u_*}{K} \cdot Log\left(\frac{j + j_0}{j_0}\right)$

j_0 being the rugosity length.

- Unsteady case :

$$\bar{U}(j) = \frac{u_*}{K} \cdot \left[2\, tg^{-1} x(j) - tg^{-1} x(0) + Log \frac{x(j)-1}{x(0)-1} - Log \frac{x(j)+1}{x(0)+1} \right]$$

with : $x(j) = \left(1 - 15.\frac{j + j_0}{L}\right)^{0.25}$

- Steady case :

for $z \leq L$, $\bar{U}(z) = \frac{u_*}{K}\left(\log\frac{z+z_0}{z_0} + \beta\frac{z}{L}\right)$

for $L < z \leq z_{CL}$, $\bar{U}(z) = \frac{u_*}{K}\left(\log\frac{z+z_0}{z_0} + \beta\right)$

while in the external zone ($z_{CS} \leq z \leq z_{CL}$) one connects by a power law the profile inside the surface layer to the geostrophic wind :

$$\frac{\bar{U} - \bar{U}_{CS}}{U_G - \bar{U}_{CS}} = \left(\frac{z - z_{CS}}{z_{CL} - z_{CS}}\right)^p$$

with $p = 0.2$ for unsteady and neutral cases
$p = 0.35$ for a low stability $(L > 30)$
$p = 0.5$ for a high stability $(L < 30)$

The determination of K_y sets many more problems : experimental results show that, on the whole, K_y is little enough variable with altitude (3). The most serious theory is that of G.I. Taylor, of which the essential result is that K_y in the vicinity of the source depends upon the distance of that source.

On the other hand, far from the source, it tends towards a constant, which depends both upon fluctuation variance of velocity $\overline{V^2}$ and upon the integral scale of the turbulence J. Now, these two quantities are badly known functions of numerous parameters. This partly explains the fact that numerous authors neglect K_y. We have preferred to keep it, giving it a constant mean value, or : $K_y = 10 m^2.s^{-1}$.

DETERMINATION OF MODEL'S PARAMETERS

These parameters were classified into three categories :

- technical parameters
- dynamical parameters
- 'traffic' parameters

TECHNICAL PARAMETERS - $K = 0.35$, $\beta = 5$

$f = 2\omega.\sin\varphi = 10^{-4}.s^{-1}$

the rugosity length z_0 can be either determined by measuring $\bar{U}$ at 2 altitudes or taken as equal to 0.02 m as proposed by some authors.

DYNAMICAL PARAMETERS : the friction velocity u_* is calculated from the datum of geostrophic wind U_G. For that, one defines a friction coefficient C_f by the relationship $C_f = u_* / U_G$

Lettau (1959) proposes the following empirical relationship, for a neutral atmosphere : C_f (neutral) $= \frac{0.16}{\log_{10} R_0 - 1.8}$ where R_0 is the number of Rossby defined by : $R_0 = U_G / f.z_0$

For taking into account the stratification effects, we shall take (Ragland 1973) :

- unstability : $C_f = 1.2 \; . \; C_f$ (neutral)
- low stability : $C_f = 0.8 \; . \; C_f$ (neutral)
- high stability : $C_f = 0.6 \; . \; C_f$ (neutral)

The Monin-Obukhov length L, used here for identifying the stratification is defined by :

$$L = -\left(u_*^3.\rho.C_p.T\right) / K.g.H$$

Taking the current mean values : $\rho = 1.2$, $C_p = 10^3$ and $g = 9.8$ and using T the value of the temperature at 10m from the ground, noted as T_{10}, we obtain $L \sim -3.10^2.\frac{u_*^3.T_{10}}{H}$

Therefore, it remains to determine the heat flow H. In the perspective which is there interesting us, that is to say for a previsional estimate, H is a datum of the problem which varies from -50 in conditions of high stability to +150 in conditions of high instability, H being zero in neutral atmosphere.

'TRAFFIC' PARAMETERS - the approach of traffic parameters has, in the present case, a statistical component, which leads to formulate a number of distribution functions peculiar to overall traffic parameters, to traffic by aircraft class or to pollutant emission factors (8).

In the traffic of an airport, there appears two separate cycles :

- a yearly cycle in regard of the monthly traffic
- a daily cycle in regard of the hourly traffic.

The 2 distribution functions are defined :

$$f(m) = \frac{\text{number of total movements during the month } m}{NMA \times \text{number of days of the month } m}$$

which characterizes the daily traffic, NMA being the yearly number of aircraft movements.

$$g(h,s) = \frac{\text{number of sequences } (s) \text{ during the hour } (h)}{\text{total number of daily movements}}$$

The sequences are five in number : idle on ground (taxiway), taking off, climbing, approach, landing.

The aircrafts are classified into 9 classes a, account taken of the characteristics and of the number of engines fitting them, of their taking off weight, of their taking off procedure, etc... One defines then a distribution function $l(a)$ characterizing the comparative traffic of class aircrafts for the considered airport and a given year.

$$l(a) = \frac{\text{number of movements of class } a \text{ aircrafts}}{NMA}$$

One then defines the emission factors $E(s,a,p)$ and $t(s)$. $E(s,a,p)$ represents the mass in kg of pollutant p emitted by a class a aircraft during a period s of which the duration is an hour. $t(s)$ is the mean duration of each sequence, defined on the basis of the E.P.A. cycle.

This enables to calculate the mass Q of pollutant p emitted during the selected hour, for a given sequence :

$$Q(m,h,s,p) = NMA.f(m).g(h,s).t(s).\sum_{a=1}^{9}\left(E(s,a,p).l(a)\right)$$

The pollutant emission takes place following straight segments, peculiar to each sequence and on which the emission is uniform.

RESOLUTION METHOD

A discrete scheme method is used. The considered zone being a parallelepiped (10km x 10km x H_I) one makes a meshing of constant pitch in x and y and of variable pitch in z. One obtains thus p_x pitch in x, p_y in y and p_z pitch in z.

The resolution method is inspired by the Varga work (9). One uses the fact that the thing is a propagation phenomenom : the concentrations in the vertical plane P, perpendicular to wind direction,

only depend upon those in the plane p-1. The source lines are discretized : at emission points, concentrations are data. Behing any source line, concentration are zero.

In each plane P, the approximations of C derived to meshing knots by the Taylor formula and the discretion of coefficients $\bar{U}$, K_y, K_z and $\frac{\partial K_j}{\partial j}$ enable to bring back the solving of equation (10) to that of a system of $p_y.p_z$ linear simple equations to unknown $p_y.p_z$. It is then necessary to solve p_x order systems $p_y.p_z$. In each plane, one returns by the Gauss-Seidel method to the solving of a fixed point equation in R^n which is solved by the method of successive approximations. The result of the calculation is a tridimensional table of C values at meshing points.

RESULTS - APPLICATIONS

RESULTS - It may be extracted from that table and the inset issued in the form of a chart of isoconcentration curves of CO, HC, NOx, within the considered area, at an altitude of 2 meters.

We have set up a number of examples for the two Airports of Paris (ORLY and ROISSY-EN-FRANCE).

This allows to compare the influence of the different meteorological conditions of different traffics or of different types of aircrafts.

In this paper, we present 4 situations :

- situation 1 : 1977 traffic (NMA = 105000)
  1 way
  with supersonic movement
- situation 2 : 1977 traffic
  1 way
  replacement of supersonic movement by B 707 movements
- situation 3 : 1985 traffic (NMA 221020)
  2 ways
  with supersonic movements
- situation 4 : 1985 traffic
  2 ways
  replacement of supersonic movement by B 707 movements.

- To each traffic situation correspond the 2 meteorological situations explained in Appendix.
- One thus obtains 8 cases, for each of which the pollution charts were drawn for the three considered pollutants.

These charts are presented in Appendix. We have plotted the landing strips. Further, the scale is the same as for runway plans.

ANALYSIS OF POLLUTION CHARTS - Experience shows that the chart geometry is very sensitive to the layout of idle taxiways which was strongly schematized : therefore, it will not be necessary to look for interpreting such point of the chart, this having not a great signification. This remark does not prejudge the concentration level analysis nor the polluted surfaces.

MAXIMAL CONTENTS - The upper limits of contents are presented and the concentrations of CO, HC and NOx are given in mg/m^3.

In 1977, under meteorological conditions favourable to the pollutant spreading, the contents were generally lower than 0.1 mg/m^3, except for CO, where the maximal contents are slightly higher.

The same year, meteorological conditions being unfavourable, the concentrations are always lower than 10 mg/m^3, whatever the pollutant.

In 1985, under favourable meteorological conditions, the contents are lower than 1 mg/m^3 for CO and NOx, than 0.1 mg/m^3 for HC, while by unfavourable meteorological conditions the upper limits are respectively under 100 for CO and 10 mg/m^3.

POLLUTION LOCALIZATION - The western area of the airport is not polluted : this is first explained by the calculation method : the velocities axles are also the time axle : pollutant do not go back in time. There is then a need to be careful not to draw too rapid conclusions.

If the width of the polluted area is measured at more than 0,01 mg/m^3, we see that it increases from West to East, to remain steady when reaching the airport center. In 1977, only one runway being in operation, that width is close to 1 or 3 km, according to favourable or unfavourable meteorological conditions ; in 1985, after opening a second runway, that area is made up of 2 strips each 1 km wide, which join together, thus forming a 5 to 6 km wide area, when the wind speed decreases and the reversion ceiling lowers.

At a 2m altitude, the polluted area covers the runway layout, the idling runways being by far the most influencing, at least for CO and HC, which is in agreement with remarks made about emissions.

CONTENT VARIATIONS - Influence of supersonic - The lack of sharpness of isoconcentration charts does not permit a close analysis : the insertion of supersonic in 1977 and 1985 traffic is translated by a general increase of carbon monoxide and hydrocarbonscontents, the polluted surfaces being almost doubled, but this insertion is practically not influencing the nitrogen oxides pollution.

Evolution from 1977 to 1985 - In each considered point, concentrations are multiplied by a factor within 1 and 10, while the surfaces also polluted are approximately doubled.

Influence of meteorological conditions - It is here that the calculation program regains its full interest : it enables us to appraise the influence of wind speed variations from 5 to 2ms^{-1} and of the reversion ceiling from 1000m (neutral case) to 100m (steady case) at a multiplying factor k close to 100 :

for CO : $10 < k < 100$
for HC : $k \sim 100$
for NOx : $60 < k < 100$.

The influence of the different flight sequences being variable, according to the pollutants, no wonder that k has different values for CO, HC and NOx.

On the other hand, the polluted area lengthen to East and considerably widen (x 3).

CONCLUSIONS

The results of this study must be used only as comparative elements for translating the impact due to the evolution of a meteorological situation or to the traffic alteration upon pollution levels and not to obtain very precise and absolute elements.

This is explained by several causes :
- the hourly traffic taken into account is a maximal mean traffic : the actual hourly traffic may be much more important
- the achieved curves are only averages over an hour : the instantaneous levels may therefore be much higher.
- the calculation meshing, peculiar to the program (500 x 500 m) being wide, we cannot sharply evaluate the concentrations, especially as the pitch of isoconcentration curves is high enough.

It would be of interest to improve the model precision by reducing the program pitch from 500 m to 200 m, for example, in order to detect more easily the areas where pollutant levels are high and to limit the action of activities responsible for the highest concentrations in ambiant air, above all idle and taxi-way operations.

Nevertheless, the analysis of emitted pollutant masses and of calculation program results allow to determine the prominent influence for pollution of the following factors :
- meteorology
- traffic alteration.

First, meteorological conditions are of prime importance upon atmospheric pollution : an unfavourable meteorological situation (slight wind, low ceiling) may multiply by 100 the concentrations at ground level. It would be interesting to calculate the concentrations for unusually unfavourable meteorological conditions, which was not done here.

Then, the increase of traffic on Charles de Gaulle Airport between 1977 and 1985 results in an increase of about 300% of CO emissions, of about 200% of HC emissions and of 170% of NOx emissions.

On the toxicological aspect, in spite of absence of standards of ambient air quality in France, it clearly appears that pollution levels due to air traffic with present aircrafts are very low, even with high supersonic traffic ; that is partially confirmed by measurements on some airports as Washington Dulles Airport (11) ; so :
- for CO, the levels cannot exceed in 1985 the American standards for air quality (10 mg/m^3 during 8 hours or 40 mg/m^3 during an hour) under unfavourable meteorological conditions, at least on runways themselves.
- for HC, the American standards for air quality set at 0.160 mg/m^3 over 3 hours are exceeded when meteorological conditions are unfavourable, and that even over a very wide area in 1985.
- for NOx, the standard is 0.1 mg/m^3 in average over a year. It seems that we do not reach it.

Although only toxicological studies can permit to conclude to CO, HC and NOx inocuity at such low levels, this prevision model denotes much lower air pollution in the vicinity of airports than near roads or highways.

At last, this prevision for 1985 is calculated with a traffic composed for a large part by present aircrafts, while the accelerated introduction of numerous low-pollution aircrafts in the coming years, such as AIRBUS 300 on Charles de Gaulle Airport will result in a large reduction of these low levels of pollution.

ACKNOWLEDGMENT

We are grateful to the "Direction Générale à l'Aviation Civile (DGAC)" for its material assistance as well as to MM J.F. Desnos and T. Dumont of the Calculation Center of the LYON-ST.ETIENNE University, who have developed the solving method and the calculation program.

REFERENCES

1. A. Daniels and W. Bach, "Simulations of the environmental impact of an airport on the surrounding air quality", J. Air Pollut. Cont. Ass., Vol. 26, p. 339-344, 1976.

2. G. Péri, "Modèle de prévision de la pollution en bordure des aéroports" Rapport 92p., I.R.T. France, 1975.

3. J.L. Lumley and H.A. Panofsky, "The structure of atmospheric turbulence" University of Rochester, Interscience publishers New York, 1964.

4. I. Van der Hoven, "Power spectrum of horizontal windspeed in the frequency range from 0.0007 to 900 cycles/hour" J. Meteor., Vol. 14, p. 160-164, 1957.

5. K.W. Ragland, "Multiple box model for dispersion of air pollutants from area sources" Atm. Environment, Vol. 7, p. 1017-1032, 1973.

6. S.R. Hanna, "The thickness of the planetary boundary layer". Atm. Environment, Vol. 3, p. 519-536, 1969.

7. J.A. Businger, J.C. Wyngaard, Y. Izumi and E.F. Bradley, "Flux profile relationships in the atmospheric surface layer". J. Atmos. Sci., Vol. 28, p. 181-189, 1971.

8. G. Péri, "Prévision de la pollution en bordure des aéroports. Modelage des sources d'émission" Rapport 43p, I.R.T. France, 1975.

9. R.S. Varga, "Matrix iterative analysis", Prentice Hall, Englewood Cliffs - New Jersey, 1972.

10. H.H. Lettau, "Wind profile. Surface Stress and geostrophic drag coefficients in the atmospheric surface layer", Advances in Geophysics, Vol. 6, 1959.

11. H. Segal, "Monitoring Concorde Emissions" J. Air Pollut. Cont. Ass., Vol. 27, p. 623-630, 1977.

12. G.B. Frame, "Simulation of airport air quality by box photochemical and gaussian models", J. Air Pollut. Cont. Ass., Vol. 28, p. 155-157, 1978

13. K.I. Weal, G.R. Thompson and D.W. Netzer, "Modification of an ambient air quality model for assessment of U.S. Naval aviation emittants", J. Air Pollut. Cont. Ass., Vol. 28, p. 247-248, 1978.

APPENDIX A

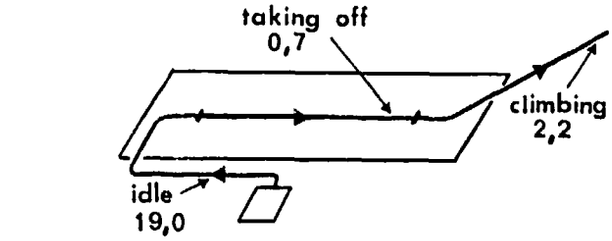
List of symbols

$A(X_i,t)$	Pollutant mass disappearing by time unit at point X_i kg.m^{-2}.s^{-1}
a	Aircraft class
C	Pollutant concentration, kg.m^{-3}
C_f	Friction coefficient
C_p	Massic heat at constant pressure, J.m^{-3} d°$^{-1}$
$\mathfrak{D}$	Molecular diffusion coefficient, m^5.kg.s^{-1}
$E(s,a,p)$	Pollutant mass p given off by an aircraft of class a during an hour of sequence s, kg.h^{-1}
f	Coriolis parameter, s^{-1}
f_{ai}	Component as for O_{xi} of Coriolis strength, m.s^{-2}
$f(m)$	Distribution function characterizing the daily traffic
g	Gravity acceleration, m.s^{-2}
$g(h,s)$	Distribution function characterizing the hourly traffic
H	Heat flow, J.m^{-2}.s^{-1}
H_I	Reversion height, m
K	Karman constant
K_x, K_y, K_z	Turbulent diffusivity coefficient, m^2.s^{-1}
K_M	Turbulent diffusivity, m^2.s^{-1}
L	Monin-Obukhov length, m
$l(a)$	Distribution function of aircraft classes
m	Month
NMA	Yearly number of aircraft movements
P	Atmospheric pressure, kg.m^{-2}
p	Pollutant, §3
$Q(X_i,t)$	Pollutant mass given off at a point X_i per time unit, kg.m^3.s^{-1}
R_O	Rossby number
s	Flight sequence
T	Temperature, d°
T_{10}	Temperature at 10 metres above ground
t	Time, s
$t(s)$	Duration (EPA) of a sequence s, h
U_{CS}	Wind velocity in the surface layer, m.s^{-1}
U_G	Geostrophic wind, m.s^{-1}
U_i, U_j	Component following the axle O_{xi}, O_{xj} of wind velocity, m.s^{-1}
u_*	Friction speed, m.s^{-1}
z_O	Rugosity length, m
z_{CS}	Height of surface layer, m
z_{CL}	Height of limit layer, m
α	Molecular diffusivity, m^2.s^{-1}
ϕ_M	Function of z/L
δ_{ij}	Kronecker's symbol
ν	Molecular diffusivity, m^2.s^{-1}
ρ	Air mass volume, kg.m^{-3}
τ_*	Friction stress, kg.m^{-1}.s^{-2}

APPENDIX B

CLASS (a)	AIRCRAFT	
1	SUPERSONIC	
2	JUMBO JET	B 747
3	JUMBO JET	DC 10
4	LONG RANGE JET	B 707-DC 8
5	MEDIUM RANGE	A 300 B
6	MEDIUM RANGE	B 727
7	MEDIUM RANGE	DC9 -B737 MERCURE
8	MEDIUM RANGE	CARAVELLE TRIDENT BAC 111
9	OTHERS	

Table 1 : Aircraft classifications system for the model -



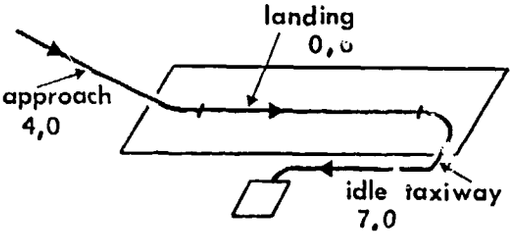


Fig. 1 Aircraft operations with time in minutes -

APPENDIX C

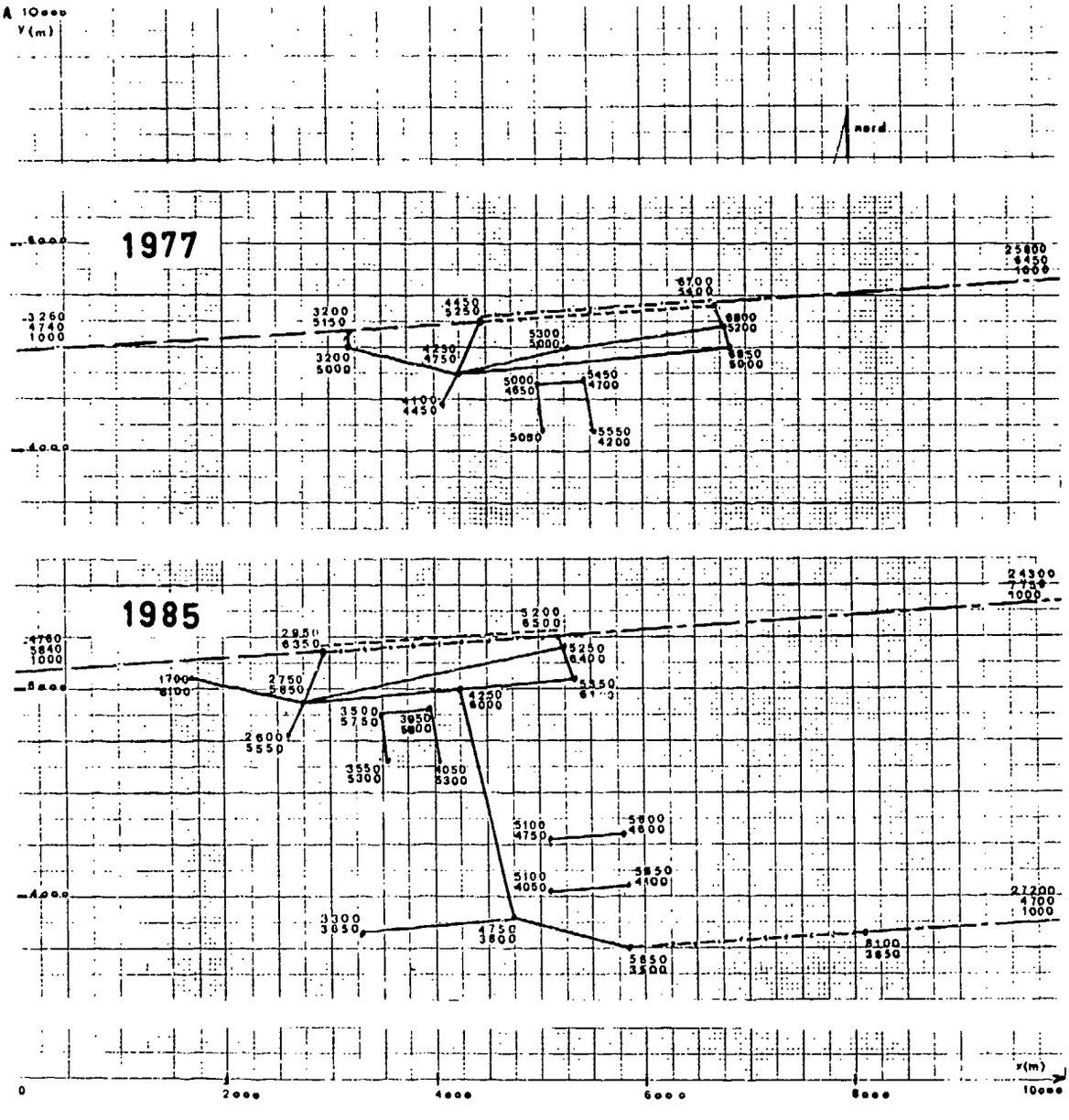


Fig. 2 Runways on Charles de Gaulle Airport in 1977 and in 1985

Indicated coordinates are x, y, z (situation of aircrafts in space)

1 idle

2 taking off

3 climbing

4 approach

5 landing

APPENDIX D

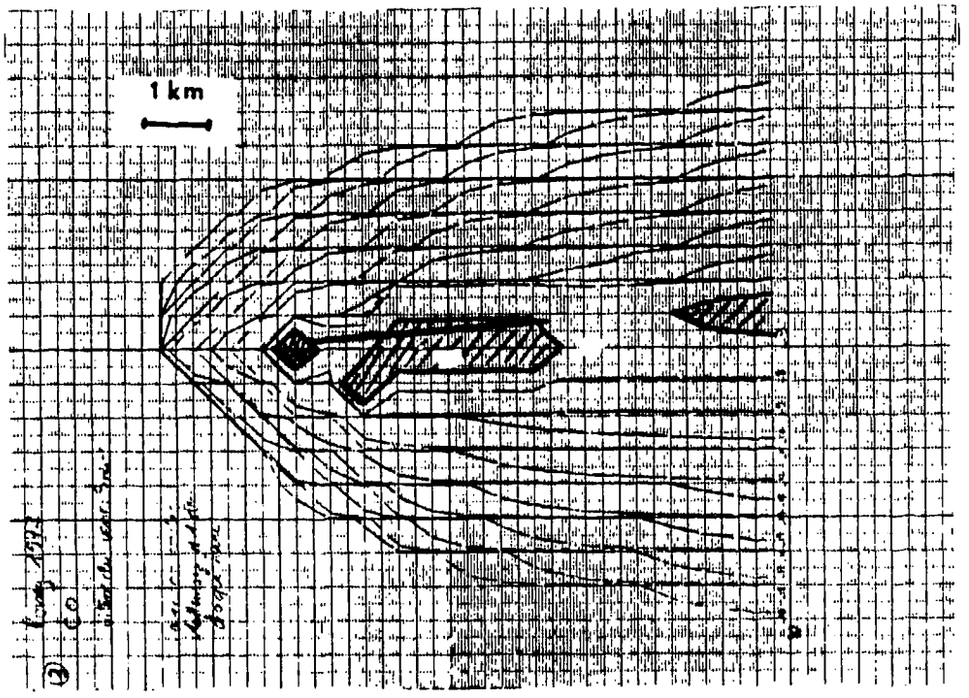


Fig. 3 Concentrations of CO at 2 meters high during 1 hour (traffic with 1 landing and taking-off of supersonic) ▨ 0,1 ⩽ CO ⩽ 1 ppm

Primary result obtained from computer for Charles de Gaulle Airport

Conditions :
- 20^{th} hour traffic 1977
- windspeed 5 m/s
- inversion height 1000
- t° 17°C

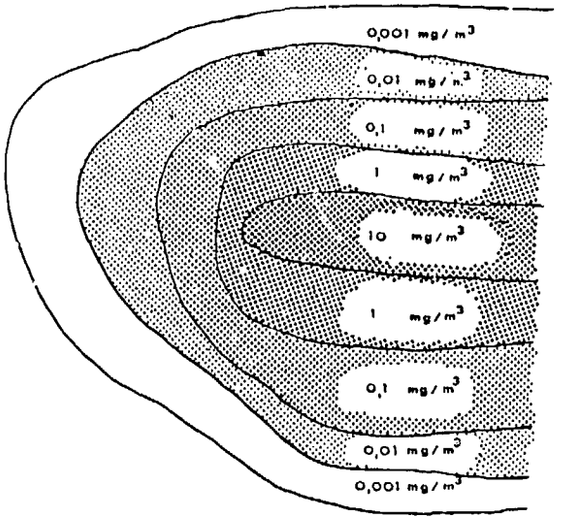


Fig. 4 Scale of concentrations for CO, HC, NOx

Concentrations showed here are the upper limits, so 0,1 mg/m³ means : 0,01 mg/m³ ⩽ 0.1 ⩽ 0,1 mg/m³

APPENDIX E

RESULTS FOR DIFFERENT TRAFFIC AND METEOROLOGICAL CONDITIONS

Atmospheric conditions

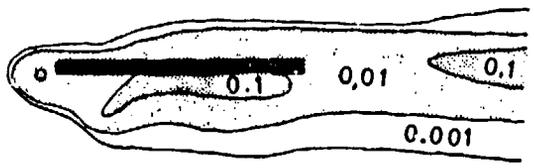
A - favourable : - windspeed 5 m/s from West
- inversion altitude 1000m
- t° 17°C

B - unfavourable : - windspeed 2 m/s from West
- inversion altitude 100m
- t° 17°C

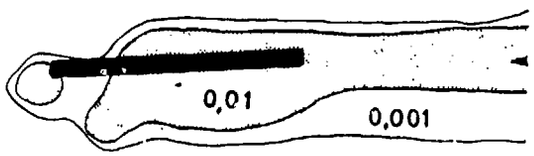
Traffic conditions during the hour

1977
1) 28 landings and/or taking-offs with supersonic movements (1 landing and 1 taking-off) (class *a*)
2) 28 landings and/or taking-offs without supersonic movements

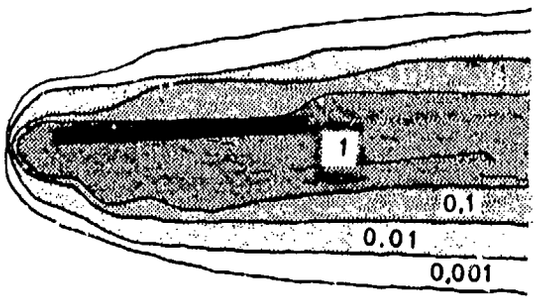
1985
1) 60 landings and/or taking-offs with supersonic movements (3 landings and 3 taking-offs) (class *a*)
2) 60 landings and/or taking-offs without supersonic movements



A CO (mg/m^3)

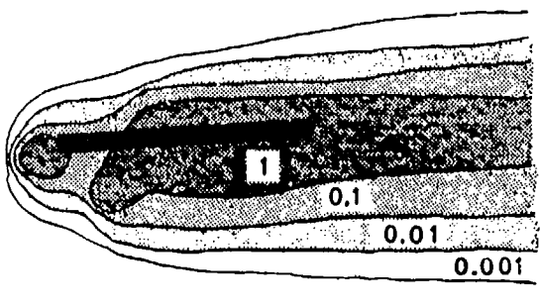


A CO (mg/m^3)



B CO

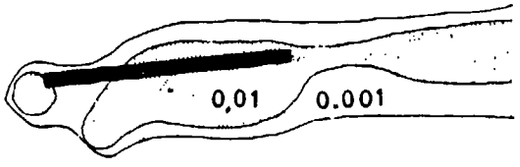
1977 with class *a* aircraft



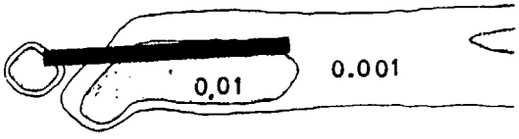
B CO

1977 without class *a* aircraft

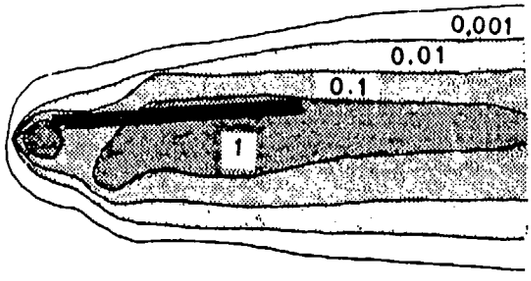
APPENDIX F



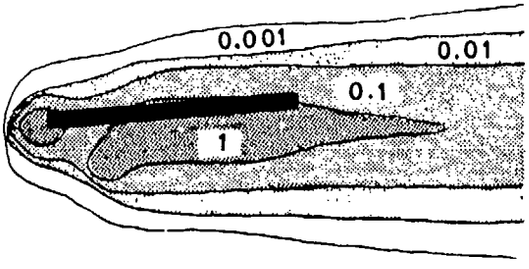
A HC (mg/m^3)



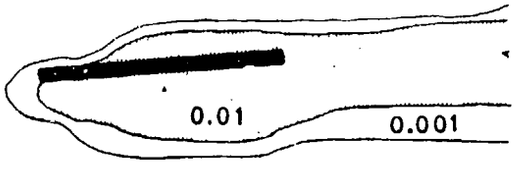
A HC (mg/m^3)



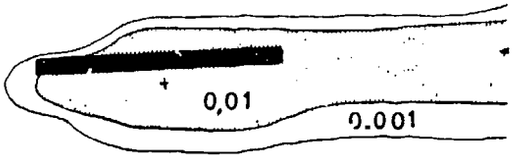
B HC



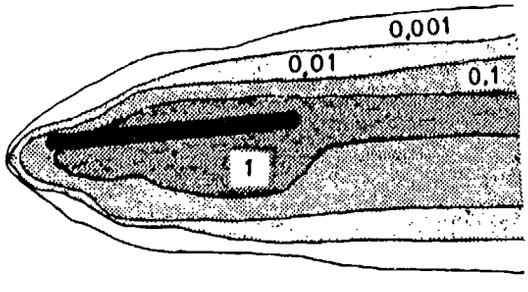
B HC



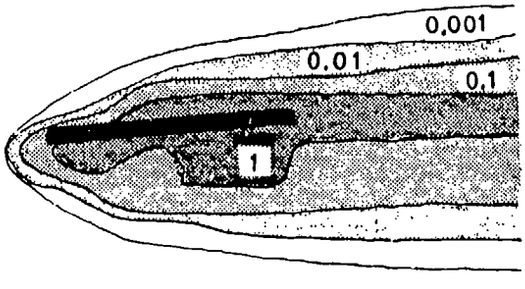
A NOx (mg/m^3)



A NOx (mg/m^3)



B NOx



B NOx

1977 with class *a* aircraft

A favourable meteorology

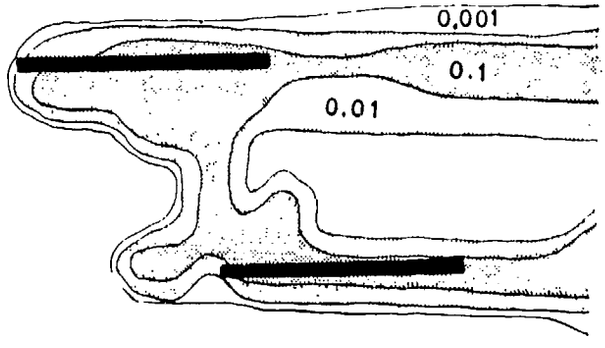
B unfavourable meteorology

197" without class *a* aircraft

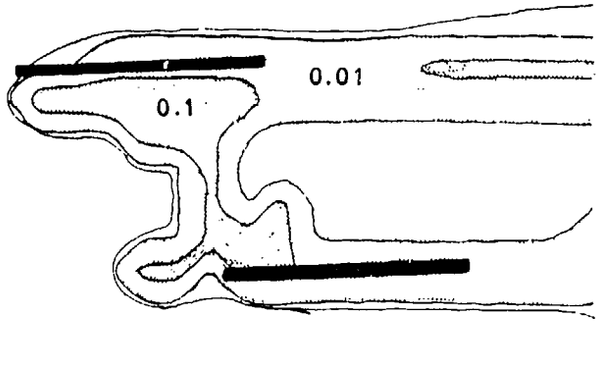
A favourable meteorology

B unfavourable meteorology

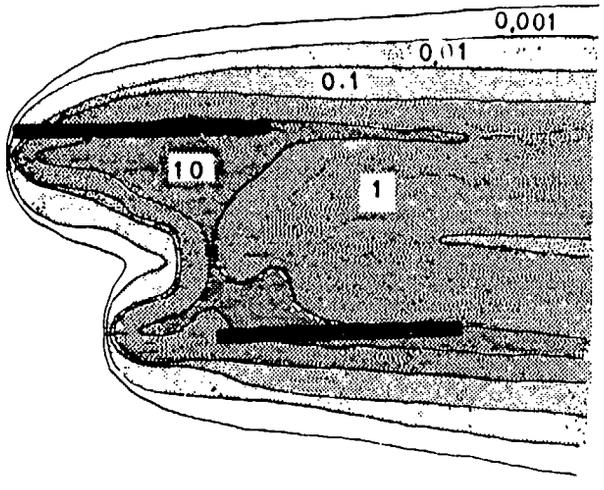
APPENDIX G



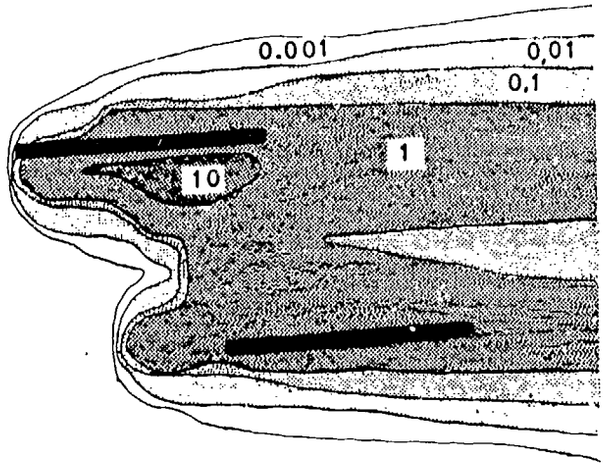
A CO (mg/m^3)



A CO (mg/m^3)



B CO



B CO

1985 with class *a* aircraft

A favourable meteorology

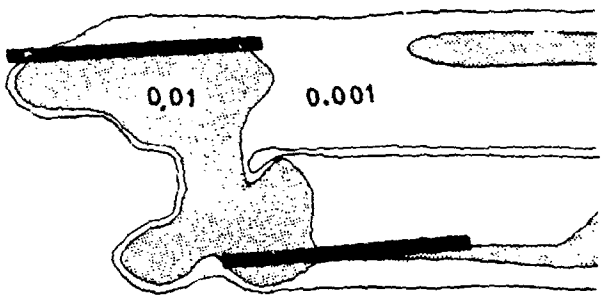
B unfavourable meteorology

1985 without class *a* aircraft

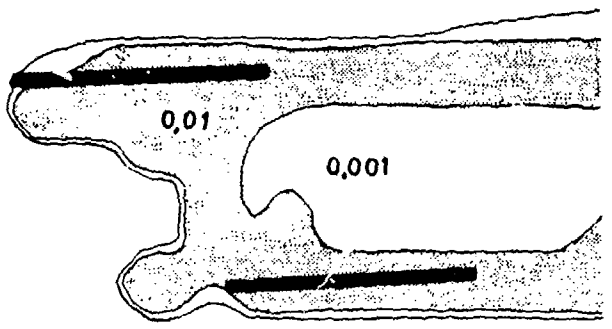
A favourable meteorology

B unfavourable meteorology

APPENDIX H



A HC (mg/m^3)



A HC (mg/m^3)

B HC

B HC

1985 with class a aircraft

A favourable meteorology

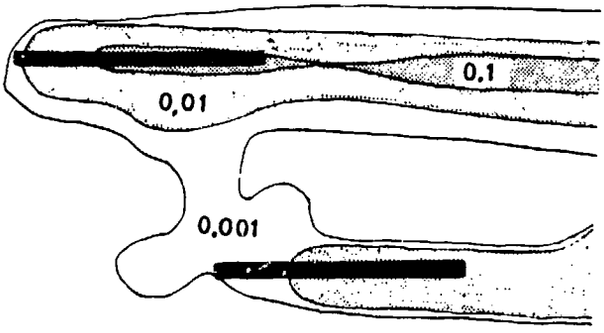
B unfavourable meteorology

1985 without class a aircraft

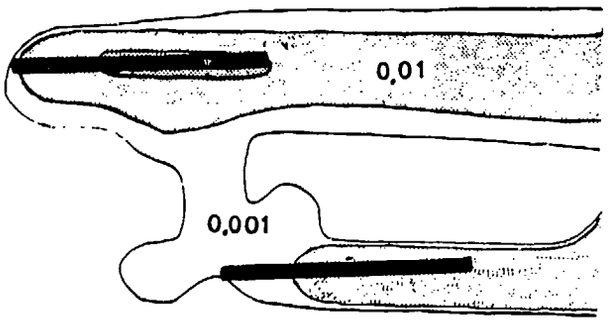
A favourable meteorology

B unfavourable meteorology

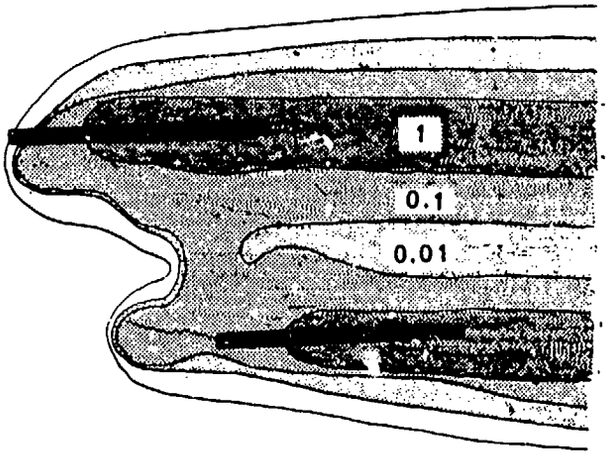
APPENDIX I



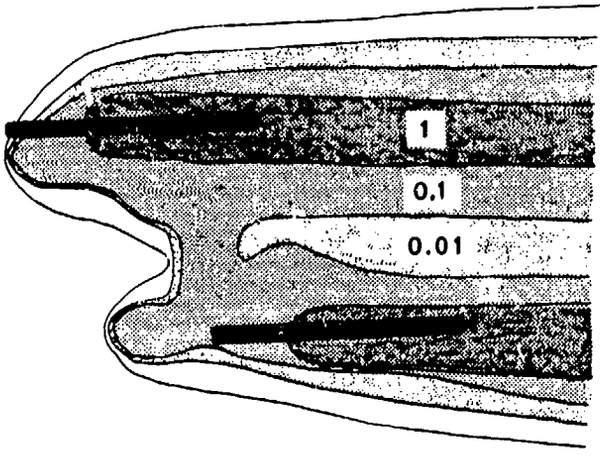
A NOx (mg/m^3)



A NOx (mg/m^3)



B NOx



B NOx

1985 with class a aircraft

A favourable meteorology

B unfavourable meteorology

1985 without class a aircraft

A favou-able meteorology

B unfavourable meteorology

DISCUSSION

D. SMITH: In your slides, you showed several different colors in the presentation. Were chey scaled to the same scale, and if so, what approximate scale was used?

DELSEY: You can find the colo.s in the paper, but at a higher level for carbon monoxide, we attain only one ppm. For hydrocarbons, one ppm is the highest value, and we cross over the American standard for hydrocarbons. For nitrogen oxide, we sometimes obtain one ppm, but in the worst condition.

ROTE: Are there any monitoring programs planned for France?

DELSEY: No.

FERRY: I object.

DELSEY: You are on the Roissy program.

FERRY: I am from the French civil aviation, and I deeply object to the answer. We have one constant monitoring program in Roissy, Charles de Gaulle Airport, and we have three mobile units which are monitoring the airport at this time.

ROTE: What pollutants are being monitored?

FERRY: CO, nitrogen oxide, and THC.

FERRY: If you look at our paper, you will see by 1985 the calculation introduced 707's as the replacement. I want to say that we are in the process of phasing out the 707 in the present fleet and there is no prospect of introducing the 707 in 1985.

DELSEY: I have to say that effectively we have measurements in Roissy but the measurements are complicated because we have a large motorway near the airport and we don't know if the pollution is coming from the motor cars or from the planes. The highway near the airport has very high traffic.

FERRY: At Roissy Airport we monitor HC, CO and NO_x, as I said previously, but we also monitor SO_2. When the wind is blowing from Paris to Charles de Gaulle, we have a very high percentage of SO_2 coming in. The major pollution at the airport comes from the pollutants which are burned by the sanitation system in Paris. I think that the major pollutants at the airport are caused by the town which is in the vicinity.

Another point here is that in 1985, I see that the aircraft engines that will be flying at that time, will be fulfilling the requirements which are printed in the ICAO Circular, so all the calculations that have been shown should be invalid because the new airplane will meet the requirements and will have a very low level of pollutant.

AQAM FOR NAVAL AIR OPERATIONS

David W. Netzer

Naval Postgraduate School
Monterey, California

ABSTRACT

Ground level pollution concentrations have been calculated at a Naval Air Station using a modified Air Quality Assessment model. The sensitivity of model predictions to varying meteorological conditions and assumed dispersion model parameters were determined. Optimum receptor locations for model validation efforts were identified.

THERE HAVE BEEN NUMEROUS modeling methods developed to predict the dispersion of air pollution. In recent years there have also been several major modeling efforts directed at aircraft operations. An early model was developed by Northern Research and Engineering Corporation (NREC) (2).* This model provided the basis for the GEOMET model (3) which has been validated to some extent by measurements at the Washington National Airport (4). Military operations (aircraft and air-base) differ significantly from civilian operations. For this reason the USAF contracted the Argonne National Laboratory to develop an air quality assessment model (AQAM) for Air Force operations (5-9). The latter model was based upon an earlier TRW Model, the Air Quality Display Model (AQDM) (10).

Most of these aircraft related models consist of three major parts, a source inventory model which yields rates and quantities of emitted pollutants, a short term dispersion model and a long term dispersion model. Many of the techniques (and their limitations) which have been used to predict the spreading rate from elevated sources have been discussed by Mathis and Grose (1). Most of the models are solutions to the diffusion equation assuming Gaussian dispersion in both the horizontal and vertical directions (1,11). In these cases the plume dimensions are specified by vertical and horizontal standard deviations (σ_y, σ_z) which in turn are functions of the atmospheric stability and the downwind distance or travel time. The models predict average steady state conentrations over some time interval; typically ten minutes or one hour for the short term models. Special provisions are made to account for very low wind speeds and the presence of elevated stable layers (lid height). Plume rise due to thermal buoyancy and vertical momentum and downwash effects are sometimes used to obtain "effective" emission heights. Most models neglect gravitational settling and chemical reactions within the atmosphere although a few consider the latter effect through a specified half-life. Short term models assume an average wind speed and direction and atmospheric stability class over the dispersion time considered.

Aircraft operations are specified through a landing and take-off operational cycle time-in-mode (LTO). The cycle is defined by the number and type of operational modes required to complete the cycle. The EPA utilizes ten, and the USAF eleven, operational modes to define an LTO cycle (12).

Accuracy of model predictions depends both upon the assumptions employed in the dispersion model and upon the detail and accuracy of the specified emission rates for aircraft, air-base and off air-base (environs) operations. Long-term models appear to agree reasonably well with observations (14). However, none of the short term models for aircraft operations have been validated as quantitatively accurate and it is doubtful that they will ever yield a good comparison with measured concentrations on an hour-by-hour basis (11, 13, 14). The values of σ_y and σ_z are not known accurately (especially in the near-source region) (11, 14), sources are not continuous, and atmospheric conditions are not steady. However, the models have been shown to be good qualitative tools for assessing the effects of changes in operating procedures and meteorology on atmospheric pollution levels (14). In addition, the short term models appear to predict frequency distributions which are in reasonable agreement with observations (14).

Regardless of the accuracy of the model for modeling the airbase operations, modeling of the surrounding environment is very difficult. It is

*Numbers in parentheses designate References at end of paper

this background level of pollution (which is typically much greater than the aircraft/air-base generated pollution) that has made it impossible to date to adequately validate any of the short term models. In addition, the cost is high in equipment and manpower to operate adequate sampling stations. A large data base is needed which includes a wide range in meteorological and operational conditions. Nevertheless, validation of the models needs to be done in as complete and well planned manner as is affordable. This is required if the models are to be used with confidence in assessing the effects of aircraft/air-base operations on both the airbase and the surrounding community.

The validation process can concentrate on high or low intensity sampling or both in some combination. It can be done for "on-base" effects or airbase effects on the local environment. Far-downwind effects caused by airbase operations require further attention. Validation efforts may consider only ground level concentrations or may include some elevated receptors. Validation can also be done for some of the sub-models within the overall dispersion model. Some of these sub-models are based upon questionable assumptions. For example, what are appropriate values for σ_y , σ_z and plume rise for the aircraft jet exhaust during taxi and take-off?

Before validation work is conducted it is necessary to determine the sensitivity of the model predictions to its input parameters (meteorology and operations). The sensitivity results indicate under what conditions the model can be best validated if only limited sampling can be accomplished. In addition, the model can be used to help locate the optimum receptor locations for model validation. The sensitivity of the model (or sub-model) to the input parameters needs to be assessed at a particular receptor location with all sources (aircraft, air-base and environ) present because of the interactions that occur between various sources (i.e. variations in "combined" concentrations of multiple sources at one receptor).

Previous model validation and sensitivity studies (14) (with only point and area sources) have shown that (a) predicted concentrations are very sensitive to the specified stability class and vary more with wind direction than observed, (b) the values of σ_z employed strongly affect the model predictions for high lid heights (2500 m), (c) the models are weak or inapplicable for low wind speeds (< 1.5 m/sec), and (d) the predicted concentrations are strongly dependent upon the lid height under unstable atmospheric conditions.

This investigation was conducted to determine the sensitivity of an air quality assessment model (AQAM) for Naval air operations (15, 16) to specified input for meteorological and operational conditions. The sensitivity study was conducted for operations at NAS, Miramar, California to precede a model validation effort at that facility which is scheduled to begin during the last quarter of 1978.

AQAM FOR NAVAL AIR OPERATIONS

The Source Inventory and Short Term Dispersion Computer Codes of the AQAM model for Air Force operations (5-9) were modified for application to Naval Air Operations (15, 16, 17). Details of the modifications are presented in references 15 and 16. Schematics of VFR and helicopter flight simulations are shown in Figures 1 and 2 (15, 16, 17).

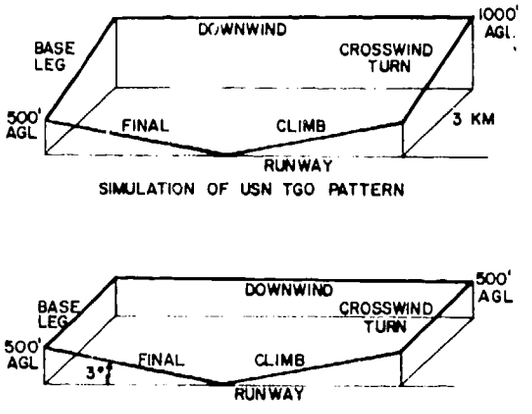
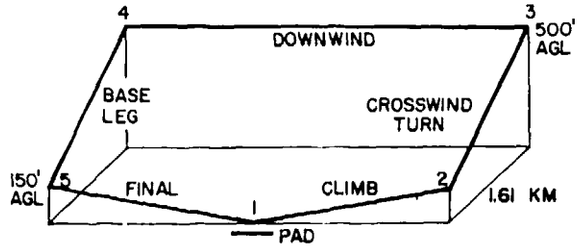
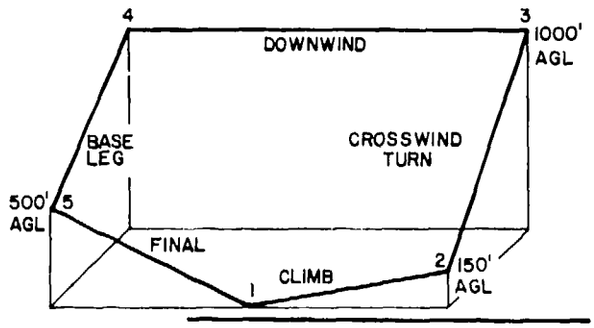


Fig. 1 - VFR flight simulations (15,16,17)

The EPA utilizes ten, and the USAF eleven, operational modes to define a LTO cycle. Take-off and landings in these LTO's were restricted to a vertical plane and did not define operational modes which are peculiar to the USN; such as hot refueling, field carrier landing practice (FCLP), Navy touch-and-go (TGO) and approaches made under visual flight rules (VFR). In addition, take-off delays and operations peculiar to rotary wing operations (hover work, pad work, autorotations) were not included in these original models. These operations were incorporated into the AQAM model and resulted in an LTO cycle with 21 operational modes as shown in Table 1.



SIMULATION OF USN HELICOPTER
PAD WORK PATTERN



SIMULATION OF USN HELICOPTER
AUTOROTATION PATTERN

Fig. 2 - Helicopter flight simulations (16,17)

Table 1. Navy LTO modes (16)

MODE OF OPERATION	SOURCE MODEL
Startup	Area
Taxi out	Line
Take off delay[a]	Area
Engine check	Area
Runway (take off) roll	Line
Climb (1+2)	Line
Approach IFR	Line
Approach VFR[a]	Line
Landing	Line
Taxi in	Line
(Hot + Pit) refuel delay[a]	Area
Hot refuel[a]	Area
Shutdown	Area
(Arrival + Departure) servicing	Area
Fuel venting	Area
Fill + spill	Area
TGO pattern[a]	Line
FCLP pattern[a]	Line
Pad work[a]	Line
Hover work[a]	Area
Autorotation pattern[a]	Line

[a]Modification to AQAM

Many of the operations added to the LTO occur at heights greater than 500 feet above ground level (AGL). These may not affect ground level pollutant concentrations near the airbase but contribute to total emissions and to pollutant concentrations at elevated heights. The latter will play increasing importance in the future as concern for far-downwind effects receives more attention.

A plot routine was also incorporated into AQAM so that predicted pollutant distribution patterns could be more readily observed over the expanded 25x16 km grid.

RESULTS OF PREVIOUS STUDY (15,16,17)

Previous studies of the effects of base operations predicted the following results for the standard grid receptors under nominal meteorological conditions:

1) Aircraft delays reduced maximum pollutant concentrations by only 2% but reduced yearly emissions by approximately 21% for CO and HC and 13% for particulates.

2) Refueling in parking areas instead of hot refueling increased local concentration levels but reduced annual emissions by approximately 8%.

3) Test cells and run up stands were the major air-base (non-aircraft) pollution source.

4) Estimated environ sources indicate that background pollution levels are high at NAS, Miramar.

MODEL SENSITIVITY STUDY

In order to determine the sensitivity of the model predictions to the input meteorological and operational conditions and to certain model parameters (σ_y , σ_z , etc.) many parameters were independently varied. The imposed variations were not intended to be simulations of actual conditions, since in most cases the variation of one meteorological condition (i.e. wind speed) affects another (i.e. stability level). The independent variations do provide valuable data for model validation.

The sources included in the model for NAS Miramar are presented in Table 2. A map showing representative grid locations is shown in Figure 3. The receptor grid employed had a one kilometer spacing.

The nominal conditions and variations employed in the sensitivity study are presented in Table 3.

Table 2

Summary of Sources at NAS Miramar

I. Air Base Sources

15 Point Sources

1 training fire
5 test cells
2 run-up stands
1 power plant
6 storage tanks

30 Area Sources

evaporative breathing
space heating
off-road vehicles
civilian vehicles

22 Line Sources

civilian vehicles

II. Aircraft Sources

18 Area Sources

6 parking
4 refueling
1 take-off delay
7 pads and hover

173 Lines

LTO modes

III. Environ Sources

1 Point Source

off-base test cell

18 Area Sources

land-use

9 Lines

roadways

Table 3

Model Parameters

	Nominal	Variations
Wind speed (m/s)	2.57	3.6, 9.27
Wind direction (cw from north)	292	272,287
Temperature (°F)	60	70
Turner stability class	1	2,3,4,5
Lid height (m)	800	100,200,400,1400
Initial line source Width for A/C taxi and runway (m)	20	15,30
Initial vertical dispersion parameter for A/C taxi and runway (m)	8	12
Average emission height for A/C taxi and runway lines (m)	4	8,16

Table 3 (Cont'd)

Initial vertical dispersion parameter for all point sources	-	x 1.5
Initial vertical dispersion parameter for all area sources	-	x 1.5
Initial vertical dispersion parameter for all line sources	-	x 1.5

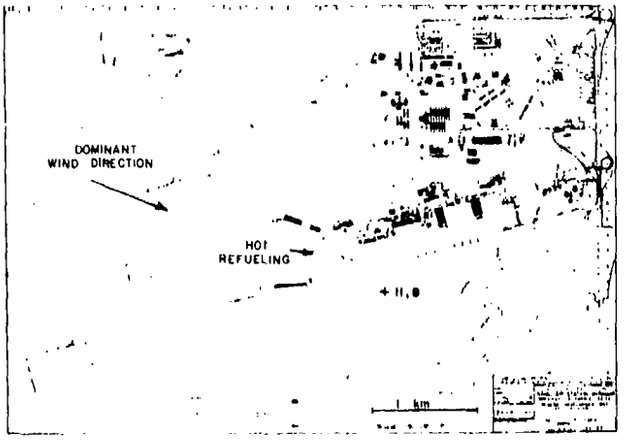


Fig. 3 - NAS Miramar

RESULTS AND DISCUSSION

GENERAL DISCUSSION - The sensitivity of the multiple source model predictions to the parameters presented in Table 3 should in general follow the Gaussian behavior for individual point and line sources. However, the behavior at a particular receptor will depend to a large extent on its location relative to the various (and numerous) sources throughout the receptor grid. From a model validation standpoint it is important that hourly average type data be collected at locations where the airbase/aircraft contributions are large compared to all environ (background) concentrations. "Optimum" receptor grids for model validation should be found which have both large air-base/aircraft contributed pollution concentrations and concentrations which are sensitive to meteorological and operational conditions. In addition, at least one (and preferably more) receptor should be located upwind of the airbase to determine background levels of pollution.

For point sources, the Gaussian dispersion formula for ground level (z = 0) concentrations has been presented by Turner (11).

$$\chi(x,y,z=0;\ H) = \frac{Q}{\pi\sigma_y\sigma_z\bar{U}} \exp\left\{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right\}\exp\left\{-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right\} \quad (1)$$

where:

χ = concentration, g/m^3
Q = uniform emission rate, g/sec
σ_y, σ_z = standard deviations of plume concentration in the horizontal and vertical directions respectively, m
$\bar{U}$ = mean wind speed, m/sec
H = plume height, m

For concentrations along the plume centerline (y = 0) the first exponential term vanishes and for ground level sources with no plume rise (H = 0) the second exponential vanishes.

When vertical diffusion is limited by a stable layer at height h_{lid} the diffusion equation must be modified. Turner (11) suggests that when the downwind distance is twice that required for σ_z to become equal to 0.47 h_{lid}, then the plume can be considered as uniformly distributed in the vertical direction. Then (1) becomes

$$\chi(x,y,z;H) = \frac{Q}{\sqrt{2\pi}\,\sigma_y\, h_{lid}\,\bar{U}} \exp\left\{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right\} \quad (2)$$

For (infinite) line sources Turner has presented:

$$\chi(x,y\ z=0;H) = \frac{2q}{\sin\phi\ \sqrt{2\pi}\,\sigma_z\,\bar{U}} \exp\left\{-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right\} \quad (3)$$

where:

q = source strength per unit distance, g/sec-m
ϕ = angle between line source and wind direction $45° < \phi \leq 90°$

Behavior of the short-term model predictions under varying meteorological conditions should in general follow equations (1), (2), or (3) depending upon the receptor location relative to the dominant emission source. At receptors where multiple sources contribute significantly the behavioral trends will not be so readily estimated a priori.

The effects of individual variations in meteorological and dispersion model parameters are discussed below in order to examine the sensitivity of the model predictions. It is not implied that these parameters can be varied independently in actual practice.

RECEPTOR LOCATIONS FOR MODEL VALIDATION - Environ sources were predicted to peak south of the airbase at receptors (11,2), (11,3), and (11,4). (11,2) is near the center of Montgomery Field and (11,4) lies due north at the intersection with Interstate 15.

For a dominant wind from the WNW (292°), nominal background (to the airbase) pollution levels were 140 $\mu g/m^3$ and 6 $\mu g/m^3$ of CO and PT respectively (special receptor #1, Table 4). Maximum background levels reached 582 and 23 $\mu g/m^3$ for CO and PT respectively for stable conditions (stability class = JSTAB = 5). More stable conditions (increasing JSTAB) decrease σ_y and σ_z and increase concentration levels (equation (1)). Lowering h_{lid} increased concentrations (equation (2)) while increased wind speeds reduced concentrations as expected.

Table 4

Effects of Meteorological and Model Parameters on Concentrations ($\mu g/m^3$) at Special Receptors

Nominal Conditions: Stability class = 1, h_{lid} = 800 m, wind direction = 292°, wind speed = 2.57 m/sec, ambient temperature = 60°F, A/C line source height = 4 m

Receptor #1 (x = 8.37km, y = 8.52km) - Background

Aircraft: $\mu \simeq o$, all conditions
Air-base: $\mu \simeq o$, all conditions

Environ: μ_{co}	μ_{pt}	Conditions
140	6	nominal
250	9	h_{lid} = 200 m
582	23	JSTAB = 5, all h_{lid}
113	4	WD = 272°
41	2	WS = 9.27 m/sec

Receptor #8 (x = 10.79km, y = 8.17km) 0.34km downwind of hot refueling area

Aircraft: μ_{co}	μ_{pt}	Conditions
574	280	nominal
592	292	other h_{lid}
1304	756	JSTAB = 5, all h_{lid}
559	270	WD = 272°
154	75	WS = 9.27 m/sec
203	119	$z_{A/C\ lines}$ = 16 m
503	248	1.5 x σ_{zo}, all line sources

Air-base: negligible

Environ:		
60	2	nominal
201	7	h_{lid} = 200 m
40	1	h_{lid} = 1400 m
321	10	JSTAB = 5, all h_{lid}
52	1	WD = 272°
17	1	WS = 9.27 m/sec

Receptor #11 (x = 12.28km, y = 8.31km) 0.08 km downwind of take-off end of runway #1

Aircraft: μ_{co}	μ_{pt}	Conditions
3496	2031	nominal
no change		$h_{lid} \leq 400$ m
9250	5297	JSTAB = 5, all h_{lid}
2918	1696	WD = 272°
904	525	WS = 9.27 m/sec
3451	2002	$z_{A/C\ lines}$ = 16 m
2965	1721	1.5 x σ_{zo}, all area sources

Table 4 (Cont'd)

Air-base:	negligible		
Environ:	54	2	nominal
	216	7	h_{lid} = 200 m
	31	1	h_{lid} = 1400 m
	296	11	JSTAB = 5, all h_{lid}
	57	2	WD = 272°
	15	1	WS = 9.27 m/sec

These background levels are high (except for particulates) compared to values at the nominal grid receptors employed and imply that model validation would be difficult except near strong aircraft and/or air-base sources. Table 4 presents data at two such special receptors (#8 and #11). Special receptor #8 is located 0.34 km downwind (for a WNW wind) from the hot refueling area and special receptor #11 is located 0.08 km downwind of the take-off end of runway #1. At these two locations aircraft sources dominate all others, indicating that they would be adequate locations for measurements to validate the model. However, receptor #11 may be too close to the emission source.

MAXIMUM RECEPTOR CONCENTRATIONS - All of the following discussion (except as noted) assumes a dominant wind from the WNW (292°). As discussed above, maximum contributions from environ sources occurred south of the airbase (at receptors (11,2), (11,3), and (11,4)). In general, the contribution from air-base sources was negligible. At receptors where air-base sources were the major contributor (downwind of test cells) overall concentration levels were quite low. However, no attempt was made to locate special receptors downwind of the test cells where concentrations may have been significant during cell operation.

Except for the special receptors discussed above, maximum concentrations from aircraft sources normally occurred for CO , HC and PT at receptor (11,8), near the intersection of runway #1 and the emergency runway. NO_x generally peaked further downwind. Stable conditions (JSTAB = 3,4) and low lid height (h_{lid} = 200m) shifted the peak concentrations downwind whereas a shift in wind direction of 20° (WD = 272°) moved the peak concentrations upwind. Larger assumed values for aircraft initial line source width also moved the peak concentrations upwind.

Fig. 4 presents typical variations in the aircraft contribution to concentrations for CO and PT in both the wind and cross-wind directions. Figures 5 and 6 present typical concentration profiles for CO and PT from aircraft sources. These profiles indicate that a good sampling location may be near the south gate of NAS, Miramar. However, at this location background levels are large compared to aircraft sources except for particulates. Apparently, only near-aircraft source receptors will yield adequate data for model validation.

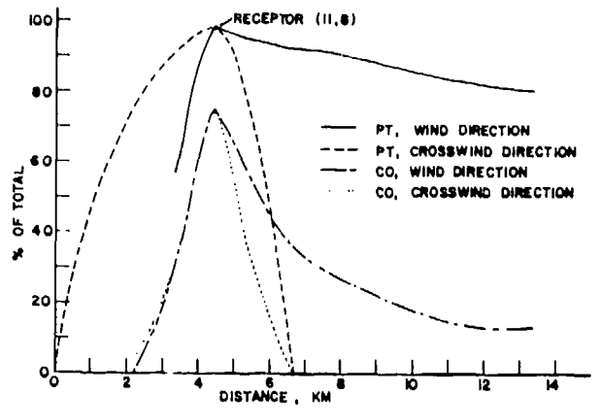


Fig. 4 - Effect of distance on aircraft contribution to receptor concentrations of CO and PT for nominal meteorological conditions

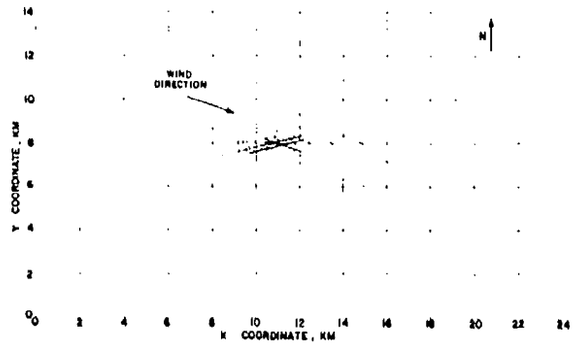


Fig. 5 - CO concentration profiles from aircraft sources

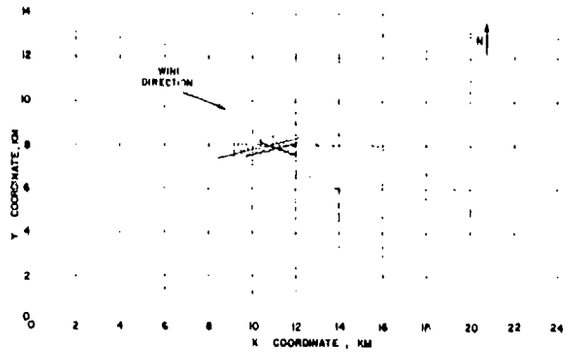


Fig. 6 - PT concentration profiles from aircraft sources

Detailed tables of results are presented in Ref. 18.

EFFECT OF METEOROLOGICAL PARAMETERS -

Lid Height - In general, environ and aircraft sources behaved in the same manner. Air-base contributions were small and varied more rapidly and less predictably. Stability class did not greatly affect the variation of concentration with h_{lid}, although it greatly affected magnitude. At near source locations (maximum receptor concentrations) variation in h_{lid} had negligible effect on concentrations except for very unstable conditions (JSTAB = 1). For JSTAB = 1, concentrations decreased less than linearly with increasing, but small values of h_{lid} (100 - 400m). For large h_{lid} (800 - 1400m) peak concentrations did not vary with h_{lid} (Fig. 7). This behavior is to be expected from equations (1) (large h_{lid}) and (2) (low h_{lid}). Also as expected, away from peak values, concentration decreased approximately linearly with increasing but small values of h_{lid} and varied little for large values of h_{lid}. As h_{lid} was increased from 200 to 400 m conditions, peak receptor locations moved upwind.

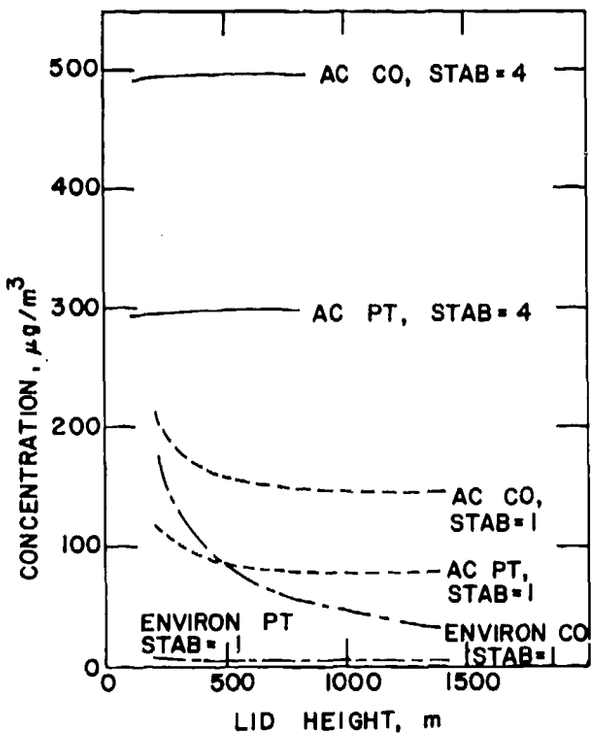


Fig. 7 - Effect of lid height on concentrations of CO and PT from aircraft sources at receptor (11,8)

Stability Class - Stability class had the single largest effect on the predicted concentrations. As stability increases (JSTAB = 1 → 5), σ_y and σ_z drop and ground level concentrations generally increase (equation (1)). Table 4 indicates that concentrations can increase by factors of 3 to 5 for JSTAB increases from 1 to 5. This is also shown in Figure 8. At special receptors, increases by as much as a factor of 10 were predicted. For large h_{lid} the effect is more pronounced than for low h_{lid}.

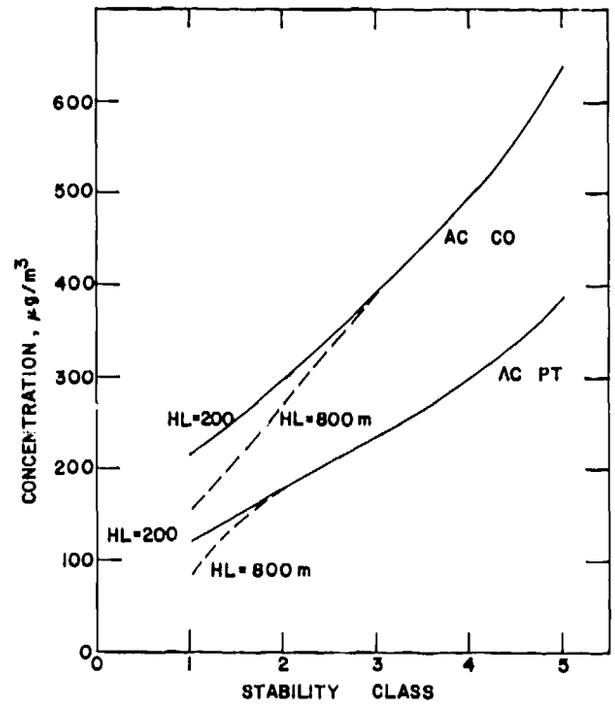


Fig. 8 - Effect of stability class on concentrations of CO and PT from aircraft sources at receptor (11,8)

Again, aircraft and environ sources behaved similarly, but air-base sources varied unpredictably with increasing stability.

Wind Speed - Increasing wind speed decreased concentrations of all sources approximately linearly as expected from equation (1), (2), and (3). More rapid variations occurred when receptors were very close to a strong source (special receptor #11, Table 4).

Wind Direction - Wind direction had negligible effect on concentrations from environ sources. As the wind direction was changed from 292° to 272° the wind became nearly parallel to the primary taxi and runway line sources. Peak concentrations from aircraft sources dropped by as much as 20% and downwind receptor concentrations increased by as much as a factor of 3.5.

Ambient Temperature - An ambient temperature change of 10°F as an independent parameter had no effect on predicted concentrations.

DISPERSION MODEL PARAMETERS -

Initial Aircraft Line Source Width - This parameter had negligible effect on concentrations from aircraft sources for nominal lid height (800m) and a stability class of 1. Effects at special receptors and for other meteorological conditions were not determined.

Aircraft Line Source Emission Height - This parameter had negligible effect for nominal meteorological conditions except at special receptor #8 (downwind of hot refueling where model validation may be attempted). At this receptor, increasing the aircraft emission height from 4 m to 16 m reduced the predicted concentrations by approximately a factor of 3. Plume rise of jet exhausts (which are neglected in the model) may have a dominant affect on model validation at particular receptors.

Initial Vertical Dispersion Parameters - Increasing (separately) the initial vertical dispersion parameters for point, area, and line sources by a factor of 1.5 had negligible effect on predicted concentrations except at near-source special receptors. Even at the latter locations predicted variations were less than 20%.

Aircraft Line Sources Above 150 m Altitude - Eliminating all aircraft line sources above 150 m altitude had insignificant effects upon predicted ground level concentrations for nominal meteorological conditions. For very low lid heights significant effects may occur, but were not investigated. The aircraft sources above 150 m do contribute significantly to the total yearly pollutants emitted by aircraft at NAS, Miramar. (approximately 8% of CO and 35% of particulates).

MODEL VALIDATION EFFORTS

Much has been written on atmospheric dispersion models and the needed validation. Some of these efforts have been discussed above. In addition to the above discussion, several additional comments are required with regard to model validation efforts.

It would be most desirable to obtain a model that could accurately predict concentration levels on an hour-by-hour basis. Obtaining such a model would be a formidable task. Current models require inputs of constant values of "properly selected" hourly averaged wind speed, wind direction, ambient temperature, lid height, and stability class. The latter is often based upon general observational type data (wind speed, cloud cover, etc.) However, it is known that vertical diffusion rates are sensitive to the vertical profile and that wind speed and direction often shift significantly during any given hour. Elevated point source dispersion data are also often used for near-ground-level point and line sources. Since σ_y and σ_z may vary significantly with elevation, large errors may be introduced. The question arises, what are "properly selected" average values for model input? Additional difficulties arise when non-continuous sources are represented as continuous sources over the one-hour period. Models should be checked for quantitative accuracy over the receptor grid of interest, but they may be of practical value even if they fail in this regard. If they can reliably predict the correct distribution of concentration values and the correct sensitivity to meteorological parameters, then such models could be used for assessing the relative effects of operations on the local environment.

It appears that many validation efforts have been directed at "complete" or "functionally efficient" models. For example, use of "observed" meteorological data to determine stability class. While this is a desired finished model characteristic, it may be far to much to ask of a model which is very sensitive to stability class. Short term model validation efforts should be conducted with very accurate operations and meteorological data. If validation fails under these conditions, the model will never be adequate for lower quality input. Accurate, and detailed meteorological data could also be used to better determine "properly selected" average values for model input.

It also appears that some "long path" measurements are required between point sampling locations to determine the validity of using point source data for validation of models that have limited microscale predictive capabilities.

CONCLUSIONS AND RECOMMENDATIONS

Ground level pollution concentrations at NAS, Miramar have been predicted using the modified AQAM model for various meteorological conditions and model parameters. Special receptor locations have been identified which appear to be ideally suited for model validation efforts.

Air-base contributions to the predicted concentrations were very small. Background (environ) source levels for all but particulates are high and will make model validation difficult except at special receptors where aircraft sources dominate (for example, downwind of hot refueling and the take-off end of runway #1).

Plume rise of aircraft jet exhausts during taxi, idle and take-off may significantly affect measured ground level concentrations. Model changes may be required to incorporate this effect.

The NAS, Miramar data incorporated into the modified AQAM model were for the year 1975 and will require updating before comparison with measured data is performed.

ACKNOWLEDGEMENT

The work reported herein was supported by the Naval Air Propulsion Center, Trenton, NJ, as part of the Naval Environmental Protection Technology Program.

REFERENCES

1. J.J. Mathis, Jr. and W.L. Grose, "A Review of Methods for Predicting Air Pollution Dispersion", NASA SP-322, 1973.

2. M. Platt, R.C. Baker, E.K. Bastress, K.M. Chug and R.D. Siegel, "The Potential Impact of Aircraft Emissions upon Air Quality", Northern Research and Engineering Corp., Final Report, Vol. 1 and 2, No. 1167-1 and 1167-2, NTIS No. PB208540, 1971.

3. S.D. Thayer, D.J. Pelton, G.H. Stadsklev and B.D. Weaver, "Model Verification - Aircraft Emission Impact on Air Quality", GEOMET, Inc. Gaithersburg, MD, Final Rept. No. EF-262, 1974.

4. S.D. Thayer, "The Development and Validation of an Airport Air Quality Model", Symposium on Atmospheric Diffusion and Air Pollution, American Meteorological Society, Santa Barbara, CA, Sept. 9-13, 1974.

5. D.M. Rote and L.E. Wangen, "A Generalized Air Quality Assessment Model for Air Force Operations", Air Force Weapons Laboratory, Kirtland, AFB, NM, Tech. Rept. No. 74-304, March 1975.

6. L.E. Wangen and D.M. Rote, "A Generalized Air Quality Assessment Model for Air Force Operations - an Operators Guide", Air Force Weapons Laboratory, Kirtland AFB, NM, Tech. Rept. No. 74-54, July 1974.

7. D.J. Bingaman and L.E. Wangen, "Air Quality Assessment Model for Air Force Operations - Source Emissions Inventory Computer Code Documentation", Argonne National Laboratory, Rept. No. CEEDO-TR-76-33, April 1977.

8. D.J. Bingaman, "Air Quality Assessment Model For Air Force Operations - Short-Term Emission/Dispersion Computer Code Documentation," Argonne National Laboratory, Rept. No. CEEDO-TR-76-34, April 1977.

9. D.F. Naugle, B.C. Grems III, P.S. Daley, "Air Quality Impact of Aircraft at 10 USAF Bases", Air Quality Research Division, Tyndall AFB, Rept. No. CEEDO-TR-76-23, April 1977.

10. TRW Systems Group, "Air Quality Display Model", NTIS No. PB 189194, Nov. 1969.

11. D.B. Turner, "Workbook of Atmospheric Dispersion Estimates", EPA Rept. No. AP-26, 1970.

12. D.F. Naugle and S.R. Nelson, "USAF Aircraft Pollution Emission Factors and Landing and (LTO) Cycles", Air Force Weapons Laboratory, Kirtland, AFB, NM, Tech. Rept. 74-303, Feb. 1975.

13. K. Zeller, "Verification of AQAM", EPA Las Vegas, NV, Internal Memorandum, 1977.

14. R.C. Koch and S.D. Thayer, "Validation and Sensitivity Analysis of the Gaussian Plume Multiple-Source Urban Diffusion Model", GEOMET, Inc., Rept. No. APTD-0935 (NTIS PB 206951), Nov. 1971.

15. K.I. Weal and D.W. Netzer, "Modification of an Ambient Air Quality Model for Assessment of US Naval Aviation Emittants", Naval Postgraduate School, Monterey, CA, Tech. Rept. NPS-57Nt 75071A, Aug. 1975.

16. G.R. Thompson and D.W. Netzer, "An Ambient Air Quality Model for Assessment of US Naval Aviation Emittants", Naval Postgraduate School, Monterey, CA, Tech. Rept. NPS-67Nt 76091, Sept. 1976.

17. Keith I. Weal, Gary R. Thompson, and David W. Netzer, "Modification of an Ambient Air Quality Model for Assessment of US Naval Aviation Emittants," APCA Journal, Vol. 28, No. 3, March 1978.

18. David W. Netzer, "Sensitivity of AQAM Predictions for Naval Air Operations to Meteorological and Dispersion Model Parameters," Naval Postgraduate School, Monterey, CA. Tech. Rept. NPS-67Nt78051,May 1978.

DISCUSSION

ROTE: What are your plans for a measurement at Miramar now?

NETZER: I think Tony could probably answer that better than we could. We had a lot of difficulties with installation, and we wanted to start, but it looks like it is going to be toward the first of the year before we start monitoring.

The effort is similar to what the Air Force has done, and we are using a lot of the same people.

BAUER: I would like to ask you some questions about stability classes. You use the Turner numeric system, which is equivalent to the P-G system. Your normal calculations are made for stability class 1 or A, but that surely can occur only a very small fraction of the time.

NETZER: I did not imply that is the normal stability class that we used for Miramar. The normal is 2. We used one only as a base case for the unstable condition in the parametric studies. In the studies that we did for looking at the effect of base operations and aircraft operations we used the actual stability class for the area, which is normally 2, or B.

BAUER: You only work in the day time don't you?

NETZER: The operations normally are essentially terminated by 1600 hours.

BAUER: The lid height is not an important parameter?

NETZER: It's usually around 800 meters.

BAUER: It doesn't affect the results, does it?

NETZER: If it get low, it affects it drastically; when it gets down below 500 meters to 400 meters, then you start to see very large effects.

TAYLOR: I noticed on one of the last couple of slides you showed CO levels of extremely high micrograms, running to 4, 5, or 6 hundred. At the same time, you predict that the air base contributions are very small. Is that because those calculated points are very central to the air base emissions and, therefore, getting a larger concentration of air base contributions?

NETZER: On that particular slide the receptor that you saw earlier is located right in the center, at the maximum point for aircraft emissions. If you look at the edge of the air base, the concentrations of CO due to the aircraft source when you are further away, two and a half, three kilometers downwind, are much, much lower.

TAYLOR: Previously you showed a contour map of CO centered on that point I believe. Do you know approximately what concentrations you are predicting at those outer rings?

NETZER: I don't remember exactly. At the peak, it is about 150 micrograms. At the edge of the air base we are talking about a number like 30.

LINDENHOFEN: I am surprised to find that where the Air Force doesn't see much of an impact of particulates, you do.

NETZER: It may be because of the difference in the aircraft operations. The Navy uses a lot of dual-engine aircraft, and a couple of them are the F-4, which is quite dirty, and the particulate concentrations from the larger number of larger aircraft, I think, dominate.

Now I need to qualify that because the data we are using for the particulate emissions come from seven- or eight-year-old reports on the particulates that are being emitted by those particular engines. They may have to be updated and the values may change, but the only real reason that I know for the big difference is the large number of multi-engine operations.

LINDENHOFEN: The Air Force has a lot of F-4's, the multi-engine aircraft.

NETZER: At Williams Air Force Base the number of dual-engine aircraft relatively speaking is quite small.

LINDENHOFEN: We are talking about other bases. Do you know what you are using for particulate mass, just soot values or are condensed hydrocarbons included?

NETZER: The values are those included in the North Island report--the aircraft emissions catalogue for those engines. Those are the values we are using. For those not available there, we have used the specs out of the 1973 Air Force report for particulates.

LINDENHOFEN: Did you model hydrocarbons?

NETZER: They were not particularly high, but higher than background, yes.

LINDENHOFEN: That is kind of strange due to the fact that the F-14's idling for 15 minutes, would generate a large amount of hydrocarbons.

NETZER: That's true, but when we modeled the work, (here it is for 1975 operations), the number of F-14 operations at Miramar was low. We have got to go back in because now the prime operator is the F-14, so we have a significant change in the input variables.

LINDENHOFEN: Thank you.

SPECIAL GUEST SPEAKER

Air Commodore Sir Frank Whittle

PRESENTATION OF FAA AWARD

BY

Mary M. Anderson
Associate Administrator for Policy and International Aviation Affairs

SUMMARY REPORT OF INVITED ADDRESS
BY AIR COMMODORE SIR FRANK WHITTLE, K.B.E., C.B., F.R.S.

Sir Frank, in his invited address, reviewed the history of his development of the turbojet engine, starting in 1930.

His initial problem was in improving the combustion efficiency of aircraft engines. He required twenty four times the combustion intensity that had ever been achieved before.

The first successful flight of the new engine took place in April 1937. The basic ingredient of the new engine was the double-sided centrifugal compressor. By June of 1939 the test version of the engine produced 1,000 pounds thrust at 16,000 rpm. The Air Ministry then contracted to build a flight version of the engine. It weighed 620 pounds and was designed for 1,240 pounds thrust.

Although people generally think there were no operational British jets during World War II, this is not true. The Air Ministry went into production of a twin-engine jet fighter called the Media. Media One was in service in 616 Squadron. Its first use was to shoot down the German buzz bomb because it was the only airplane capable of overtaking it.

In October 1941, the W1X engine and drawings of the W2B engine were flown to the U.S. for production. In six months GE had their first version of the W2 running. Bell Aircraft built the airplane with the new engine and it made its first flight on October 2, 1942. That aircraft was the XP59A and it is now in the Air and Space Museum together with the W1X engine.

Later developments of the basic engine led to the Rolls Royce Five. This engine was installed in the Media. It gave 3,600 pounds of thrust and the Media took the world speed record at 606 miles per hours.

Sir Frank's engine development group was nationalized in 1944 and in 1946 it was converted into the National Gas Turbine Establishment. Following that, Sir Frank became technical advisor to the Air Ministry.

Sir Frank's last wartime jet engine was converted to use in a transatlantic civil airplane, which was to cruise, with turbine fans, at about 450 miles per hour. The Air Ministry discouraged this effort saying that passengers wouldn't want to fly faster than 250 miles per hour. Another venture that was cut short was the Miles M52 supersonic airplane designed for 1,000 miles per hour. The Air Ministry said it was too risky for a man--even a test pilot --to fly a supersonic airplane.

Air Commodore Sir Frank Whittle was awarded the FAA Extraordinary Service gold medal by Mary M. Anderson, Associate Administrator for Policy and International Aviation Affairs during a special luncheon at the Conference. Sir Frank was honored for his pioneering efforts in developing the turbojet engine.

PHYSICAL MODELING OF SHORT-RANGE ATMOSPHERIC DISPERSION

Jack E. Cermak
Fluid Dynamics and Diffusion Laboratory

Fluid Mechanics and Wind Engineering Program
Colorado State University
Fort Collins, Colorado 80523, USA

ABSTRACT

Boundary-layer or meteorological wind tunnels capable of simulating natural winds in the atmospheric boundary layer have been developed that provide a reliable, convenient and economical means for investigation of short-range atmospheric dispersion. In particular, when dispersion through advective transport by complex mean flow over buildings and topographic features is as important as turbulent diffusion, physical modeling becomes essential for estimating the impact of a proposed developmental project on air quality. Current techniques for modeling natural wind, for simulating source characteristics and for tracer-gas analysis enable quantitative concentration data to be obtained within an accuracy of approximately 20%. Flow visualization with smoke provides complementary information that reveals details of complex interactions between the effluent and geometrical features of the site.

BOTH THE MEAN AND TURBULENT MOTIONS of the atmosphere contribute to the dispersion or dilution process. The length scales associated with these motions for the entire process span a tremendous range--approximately 10^{-4} to 10^{6} m or from molecular to global scales. A large number of the pollution-level predictions or controls that engineers are called upon to make are associated with a smaller range of length scales--approximately 10^{-3} to 10^{-5} m or from micro- to meso-scale. In this paper attention is focused on short-range dispersion over urban areas or complex terrain where the source-receptor distance may vary from 1 to 10^{4} m. For this class of flows advective transport by mean motion may contribute as much or more to dispersion as does turbulent diffusion. For these cases the most active scales of atmospheric motion probably range from 10^{-2} to 10^{4} m. Many common problems such as determination of pollutant concentrations resulting from agricultural burning, industrial-stack emissions in and near urban areas, automobile exhausts released in city streets or from elevated and underground parking garages, air-conditioning exhausts from buildings, aircraft exhausts near airports, and power-plant emissions over complex terrain are in this category.

In principle, it is possible to compute concentrations from a particular pollutant source if the wind field is specified in space and time. This detailed air-flow information is not accessible. The result has been that analytical approaches have been confined essentially to use of statistical descriptions of atmospheric turbulence for unidirectional mean flow over plane boundaries of uniform roughness and temperature (1, 2, 3)*. Unfortunately, the common air-pollution problems referred to exist where the boundaries are non-planar (topographic features such as hills and valleys may be present) and the surface roughness and temperature may be highly non-uniform (particularlt for large urban areas). Furthermore, the sources may be located near a roughness element such as a building or group of buildings where the initial dispersion is governed by complex flow over the element. The inability to describe three-dimensional mean velocity fields and turbulence characteristics for these complex but real boundary conditions has stimulated efforts to obtain concentration distributions directly. This may be accomplished by making concentration measurements in the real atmosphere or in a simulated atmospheric boundary layer created by means of a physical model.

Laboratory simulation of atmospheric motions over limited scale ranges has been used to study many fundamental meteorological processes. A general review of efforts to simulate the various scales of motion ranging from molecular to global has been presented by Hidy (4). Simulation of micro- to meso-scale atmospheric motions by means of specially designed wind tunnels has been described by Cermak (5). These reviews reveal clearly that no single laboratory model can represent the entire range of atmospheric motions simultaneously.

The primary purpose of this paper is to show through basic similarity analysis and comparisons of model and full-scale data that atmospheric transport by micro- to small-scale motions can be physically modeled in "boundary-layer" wind tunnels for a range of real boundary conditions which have great practical importance with respect to air-pollution studies. The scales of motion most accurately simulated depend upon the model scale, thermal stratification, and wind-tunnel characteristics; therefore, the distances over

*Numbers in parentheses designate References at end of paper.

which concentration distributions can be modeled accurately must be examined for each case. Comparisons of concentration data for laboratory models ranging in scale from 1:100 to 1:10,000 and their atmospheric prototype are presented when measurements in the full-scale system are available. These comparisons support the arguments for similarity of the physical model. A second objective is to illustrate the application of simulated natural wind to investigation of dispersion problems. The use of wind tunnels for physical modeling of a wide variety of wind effects encountered in wind engineering has been described by Cermak (6).

REQUIREMENTS FOR SIMILARITY

A physical model which exactly simulates the entire atmosphere is neither possible nor necessary for the study of air-pollution problems such as those identified previously. Motion in the lower atmosphere--the atmospheric boundary layer--dominates dispersion from sources near the ground; therefore, requirements for similarity of this layer must be considered.

THE PHYSICAL MODEL-The basic physical model considered in this paper is a boundary layer formed over the floor of a long wind-tunnel working section in which vertical temperature gradients are controlled by heating or cooling the floor and cooling or heating the ambient air stream. The effects of radiation transfer and phase changes of water in the atmosphere are not included in the physical model. Accordingly, neither simulation of local singular motions associated with thunderstorms and tornadoes nor washout and rainout by precipitation are achieved. The development of elevated inversion in the boundary layer either by ground radiation or by subsidence of the upper atmosphere is of extreme importance. These must be included in the model as an upwind boundary condition since the local physical process for their development are not usually present in the model.

Requirements for similarity of the atmospheric and wind-tunnel boundary layers can be obtained directly from the fundamental equations for conservation of mass, momentum and energy. These requirements have been formulated by Cermak (5) for boundary layers which are either stable, unstable or neutral over the entire boundary-layer depth. In the following paragraphs, the requirements are summarized and extend to boundary layers which have thermally stratified layers of different stabilities.

INSPECTIONAL ANALYSIS-The general requirements for geometric, dynamic and thermic similarity can be obtained directly by inspectional analysis--a method described by Ruark (7) to supplement dimensional analysis. Appropriate equations expressing the fundamental concepts of mass, momentum and energy conservation for motion of the atmosphere are the following:

Conservation of mass--

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = 0 \qquad (1)$$

Conservation of momentum (equations of motion)--

$$\frac{\partial \bar{U}_i}{\partial t} + \bar{U}_j \frac{\partial \bar{U}_i}{\partial x_j} + 2\varepsilon_{ijk}\Omega_j \bar{U}_k = -\frac{1}{\rho_o}\frac{\partial \bar{P}}{\partial x_i} - \frac{\bar{\Delta T}}{T_o} g\delta_{i3} + \nu_o \frac{\partial^2 \bar{U}_i}{\partial x_k \partial x_k} + \frac{\partial (-\overline{u_i' u_j'})}{\partial x_j} \qquad (2)$$

Conservation of energy--

$$\frac{\partial \bar{T}}{\partial t} + \bar{U}_i \frac{\partial \bar{T}}{\partial x_i} = \left[\frac{k_o}{\rho_o C_{p_o}}\right] \frac{\partial^2 \bar{T}}{\partial x_k \partial x_k} + \frac{\partial (-\overline{T' u_i'})}{\partial x_i} + \frac{\phi}{\rho_o C_{p_o}} \qquad (3)$$

Equation (2) is the time averaged equation of motion in which instantaneous dependent variables are represented as a mean value plus a fluctuation from the mean and the Boussinesq approximation has been made to express the effect of temperature stratification upon the body force. The Boussinesq approximation limits equation (2) to flows in which $\Delta T \ll T_o$ and results in $\bar{P}$ being the departure of the mean pressure from the hydrostatic pressure. In equation (3) the dissipation of kinetic energy associated with the mean and turbulent motion to thermal energy is represented by ϕ. Each of the independent and dependent variables may be scaled as follows to yield non-dimensional forms (designated by the asterisk): $\bar{U}_1 : U_o$, $u_i' : U_o$, $x_i : L_o$, $t : L_o/U_o$, $\rho : \rho_o$, $\Omega_j : \Omega_o$, $\bar{P} : \rho_o U_o^2$, $\Delta\bar{T} : \Delta\bar{T}_o$, $\bar{T} : \Delta\bar{T}_o$, $\bar{T}' : \Delta\bar{T}_o$, and $g : g_o$. The following dimensionless statements for conservation of mass, momentum and energy, respectively, result:

$$\frac{\partial \rho^*}{\partial t^*} + \frac{\partial (\rho^* u^*_i)}{\partial x_i^*} = 0 , \qquad (4)$$

$$\frac{\partial \bar{U}_i^*}{\partial t^*} + \bar{U}_j^* \frac{\partial \bar{U}_i^*}{\partial x_j^*} + \left[\frac{L_o \Omega_o}{U_o}\right] 2\varepsilon_{ijk}\Omega_j^* \bar{U}_k^* = -\frac{\partial \bar{P}^*}{\partial x_i^*} - \left[\frac{\Delta \bar{T}_o}{\bar{T}_o}\frac{L_o g_o}{U_o^2}\right] \Delta\bar{T}^* g^* \delta_{i3} + \left[\frac{\nu_o}{U_o L_o}\right] \frac{\partial^2 U_i^*}{\partial x_k^* \partial x_k^*} + \frac{\partial (-\overline{u_i' u_j'})^*}{\partial x_j^*} , \qquad (5)$$

and

$$\frac{\partial \bar{T}^*}{\partial t^*} + \bar{U}_i^* \frac{\partial \bar{T}^*}{\partial x^*} = \left[\frac{k_o}{\rho_o C_{po} \nu_o}\right] \left[\frac{\nu_o}{L_o U_o}\right] \frac{\partial^2 \bar{T}^*}{\partial x_k^* \partial x_k^*} + \frac{\partial (-\overline{T' u_i'})^*}{\partial x_i^*} + \left[\frac{\nu_o}{U_o L_o}\right] \left[\frac{U_o^2}{C_{po}(\Delta \bar{T})_o}\right] \phi^* . \qquad (6)$$

If the boundary-layer thermal stratification consists of a lower unstable layer (mixing layer) of thickness H_1 with an upper stable layer of thickness H_2, the foregoing equations can be scaled for each layer. For the lower layer $L_o = H_1$, $U_o = (U_o)_1$, $\Delta\overline{T}_o = (\Delta\overline{T}_o)_1$ and $\rho_o = (\rho_o)_1$ while for the upper layer $L_o = H_2$, etc.

GEOMETRIC, DYNAMIC AND THERMIC SIMILARITY- One set of requirements for exact similarity is equality of the nondimensional coefficients (quantities in brackets) shown in equations (4), (5) and (6) for the physical model and the atmosphere. In summary, the requirements may be stated as follows:

a. Undistorted scaling of geometry--equation (4) contains no dimensionless multipliers composed of the scaling factors because all length variables were scaled with the same length L_o. Accordingly a model of undistorted geometry will produce a flow which will be compatible with the principal of mass conservation.

b. Equal Rossby number--$Ro = U_o/(L_o\Omega_o)$

c. Equal gross Richardson number--$Ri = (\Delta\overline{T}_o/T_o)\ (L_o/U_o^2)g_o$--if the atmospheric flow is composed of two layers of different stratification, two Richardson numbers, say Ri_1 and Ri_2, are required to specify similarity requirements.

d. Equal Reynolds number--$Re = U_oL_o/\nu_o$

e. Equal Prandtl number--$Pr = \nu_o/(k_o/\rho_oC_{po})$

f. Equal Eckert number--$Ec = U_o^2/(C_{po}\Delta\overline{T}_o)$

The possibility of meeting these requirements in the laboratory and approximations introduced through partial fulfillment of the exact similarity requirements will be discussed later.

SIMILARITY OF BOUNDARY AND INITIAL CONDITIONS- The foregoing requirements must be supplemented by the stipulation that the surface boundary conditions and the approach flow characteristics be similar for the atmosphere and its model. Similarity of initial conditions (approach flow characteristics) pertaining to the mean and turbulent velocities is often referred to as kinematic similarity required similarity of the following features:

a. surface-roughness distribution;

b. aerodynamic effects of surface roughness elements corresponding to an "aerodynamically rough" surface; and

c. surface-temperature distribution.

Similarity of the approach flow characteristics require similarity of the following elements:

a. distributions of mean and turbulent velocities;

b. distributions of mean and fluctuating temperatures;

c. the longitudinal pressure gradient (should be zero); and

d. equality of the ratio H_2/H_1 if the flow is layered.

If all the foregoing requirements were met, all scales of motion ranging from micro- to meso-scale, 10^{-3} to 10^5 m, could be simulated

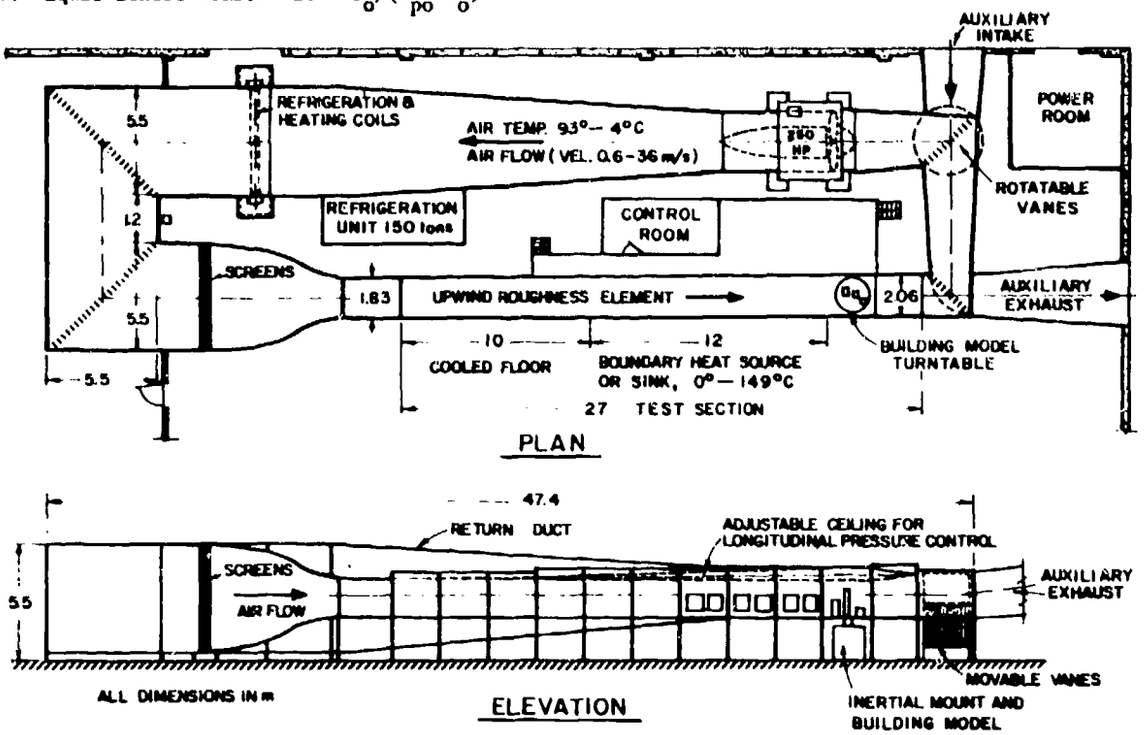


Fig. 1 - Meteorological Wind Tunnel--Fluid Dynamics and Diffusion Laboratory, Colorado State University

simultaneously. The diffusion process could then be accurately reproduced over horizontal distances up to 10^5 m within the planetary boundary layer. However, all of the requirements cannot be met by existing laboratory facilities and partial on approximate simulation must be used.

LABORATORY CAPABILITIES FOR PHYSICAL MODELING

The range of capabilities for simulation of the atmospheric boundary layer over a variety of thermal stratifications is closely related to characteristics of the wind-tunnel used. Simulation capabilities will be discussed in relation to the most versatile wind tunnel now in operation which was designed for this purpose.

WIND-TUNNEL CHARACTERISTICS-Plan and elevation views of the meteorological wind tunnel are shown in Fig. 1. Details of the flow facility are presented by Cermak (8) and Plate and Cermak (9). The gross characteristics of this wind tunnel are as follows:

a. air speed (ambient in test section): 0.1-30 m/s;

b. air temperature (ambient in test section): 5-95°C;

c. turbulence intensity (ambient in test section): 0.05%;

d. boundary temperature (test-section floor): 1-200°C; and

e. longitudinal pressure gradient: adjustable to zero.

The measurements of Zoric and Sandborn (10) shown in Fig. 2 for neutral flow over a smooth boundary reveal that the vertical distributions of mean velocity, turbulence intensities and Reynolds shear stress become similarity distributions for downwind distances exceeding about 10 m. This condition holds when the boundary conditions are uniform over the entire test-section length and the boundary-layer thickness δ is used to scale vertical distances from the boundary. Accordingly, the turbulent flow properties for the lower 10-15% of the boundary layer exhibit near homogeneity in planes parallel to the lower boundary for downstream distances over 10 m. The atmospheric surface layer exhibits a similar property at distances sufficiently far downstream from changes in surface roughness or temperature. Boundary-layer thicknesses over the downstream 5 m are influenced strongly by the surface roughness. For an ambient wind speed of 10 m/s and uniform roughness over the entire test-section floor, the following boundary-layer thicknesses have been measured (11):

Roughness Height (m)	Boundary-Layer Thickness (m)
"Smooth"	0.70
0.02	1.10
0.02	1.32

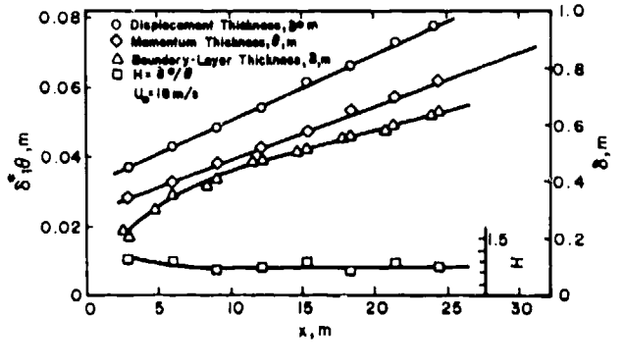


Fig. 2 - Mean-velocity profile parameters for meteorological wind tunnel (10).

Characteristic distributions of turbulent energy with wave numbers for motion in the wind-tunnel boundary layer are shown in Fig. 3. When compared with the atmospheric data using Kolmogorov scaling, excellent similarity is found to exist down to a wave number determined by distance above the boundary, roughness height and wind-tunnel size. Comparisons of other flow characteristics such as mean velocity, intensity of vertical turbulent motion, turbulent energy dissipation rates are given in references (5), (11) and (12).

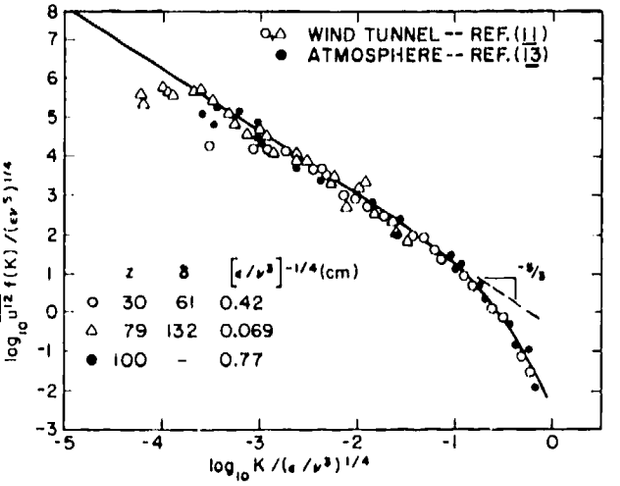


Fig. 3 - Spectrum of longitudinal component of turbulence.

Another type of wind tunnel capable of developing a satisfactory boundary layer for atmospheric simulation is shown in Fig. 4. The disadvantages of the open-circuit wind tunnel is that thermal stratification and disturbance-free flow are more difficult to obtain. However, a stable thermal stratification can be obtained through the addition of a dry-ice layer at the test-section entrance.

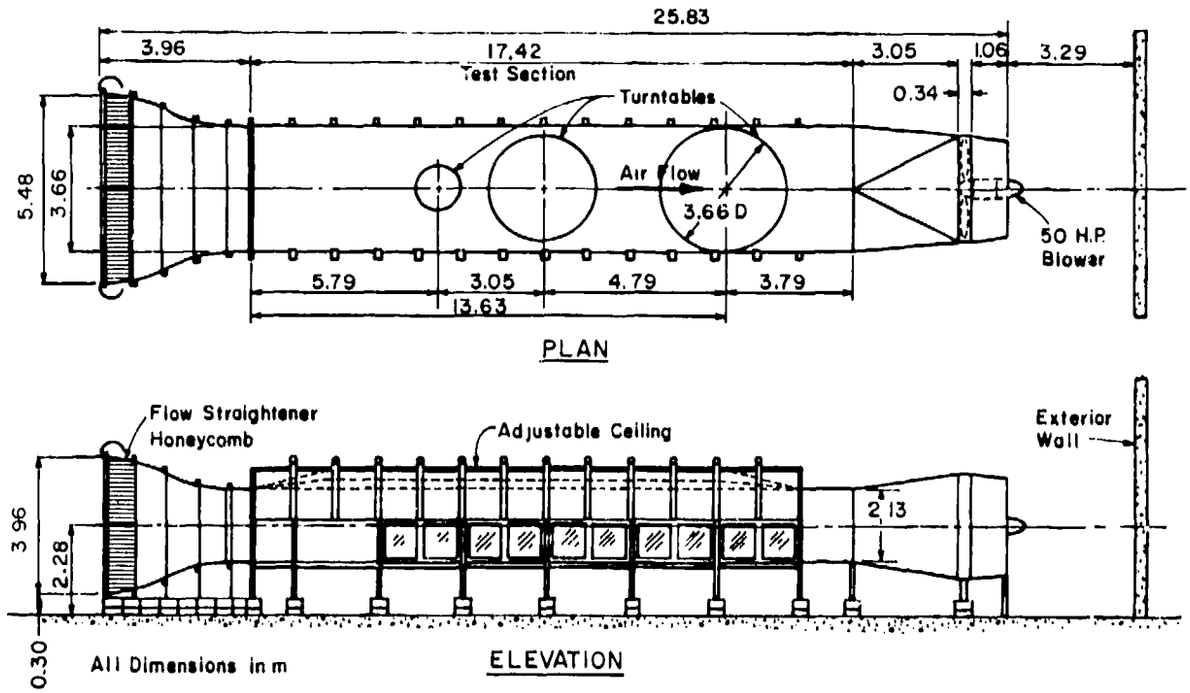


Fig. 4 - Environmental Wind Tunnel--Fluid Dynamics and Diffusion Laboratory, Colorado State University.

ATTAINABILITY OF EXACT SIMILARITY REQUIREMENTS-Wind-tunnel flow characteristics and physical size are such that most of the requirements for similarity with the atmosphere only can be approximated with varying degrees of accuracy. This does not eliminate the possibility of making useful studies of diffusion by means of small-scale models but limits the range of length scales and thermal conditions for which the studies are feasible. Each similarity requirement will be examined in an effort to determine the necessary approximations imposed by the physical model and the resulting limitations imposed upon the air-pollution studies.

Undistorted Scaling of Geometry-Selection of equal length scales for horizontal and vertical distances results in an undistorted model. Such a model is usually used unless the scale is so small (less than 1:1000) that the surface with scaled surface-roughness elements becomes an aerodynamic smooth surface. In this case, a local distortion through increase in height of roughness elements is necessary to produce an aerodynamically rough surface. No limitations on possible air-pollution studies result from this requirement.

Equal Rossby Number-The ratio of model and atmospheric Rossby numbers is $U_{om}L_{oa}/(U_{oa}L_{om})$ since the wind tunnel (unless placed upon a rotating platform) has the same angular velocity as Earth. Accordingly, the flow effects produced by rotation of Earth is not reproduced since the Rossby-number ratio will be in the range $10^2 - 10^4$. This limits the simulation to atmospheric flows not affected appreciably by rotation of Earth. Using a Rossby number of 10 and greater to express this condition, the following broad guidelines for atmospheric flow which may be simulated without large error due to Rossby-number inequality are the following:

U (m/s)	L (m)	Model Scale (approx. minimum)
> 0.1	10^2	1:100
> 1.0	10^3	1:1,000
>10.0	10^4	1:10,000

Equal Gross Richardson Number-Exact similarity of density stratification is essential for realistic simulation of atmospheric motion. Bulk Richardson numbers over a layer 0.10 m deep can range from -0.5 to 0.5 in the meteorological wind tunnel to cover a wide range of atmospheric conditions. This requirement does not limit to any significant extent the atmospheric flows which can be simulated.

Equal Reynolds Number-The ratio of Reynolds number for the wind-tunnel model and the atmospheric Reynolds number is $U_{om}L_{om}\nu_{oa}/(U_{oa}L_{oa}\nu_{om})$. This ratio varies from 10^{-2} to 10^{-4} and depends primarily upon the model scale. Fortunately, flow characteristics over rough surfaces become independent of Reynolds number for Reynolds numbers larger than a value which depends upon the roughness of the surface (14). Fig. 5 gives the minimum roughness as a function of the approach-length Reynolds number U_oL_1/ν_o for Reynolds-number independence of the drag coefficient in thermally neutral flow. These conditions for Reynolds-number independence can be met readily for neutral and unstable flow.

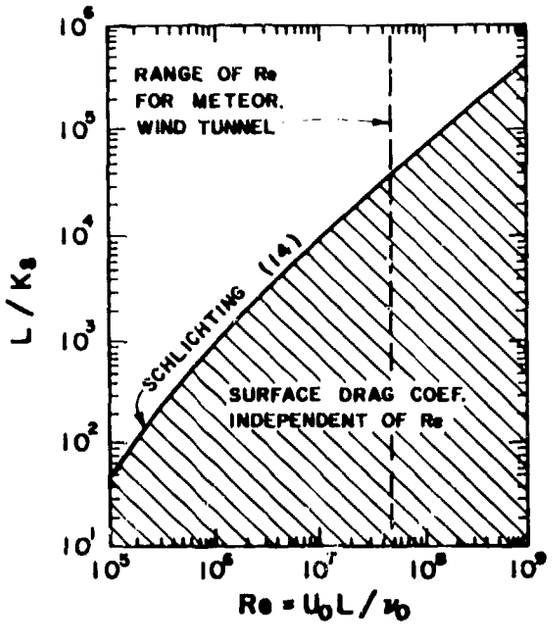


Fig. 5 - Reynolds-number independence of the surface drag coefficient as a function of relative roughness in neutral flow.

Equal Prandtl Number-The requirement of equal Prandtl numbers for the two flows is met exactly when using air as the wind-tunnel fluid. Over a temperature range of -100°C to 100°C this number varies only from 0.75 to 0.70. Accordingly, this requirement does not restrict the flows which can be simulated

Equal Eckert Number-The Eckert number appears as a product with the reciprocal of Reynolds number and enters into similarity requirements only for thermally stratified flows. Although the Eckert number cannot be made equal for the two flows, the entire dimensionless coefficient of the dimensionless dissipation in equation (3) may be nearly equal. For example, when equality of Richardson numbers is achieved (this is a prime requirement), a length-scale ratio of 10^{-3} requires that $U_{om}/U_{oa} = 10^{-1}$ and $(\Delta\bar{T})_{om}/(\Delta\bar{T})_{oa} = 10$. The ratio of dissipation coefficient for model and atmosphere has the form $(U_{om}/U_{oa})\,(L_{oa}/L_{om})\,(\Delta T_{oa}/\Delta T_{om})\,(\nu_{om}/\nu_{oa})\,(C_{poa}/C_{pom})$. For the magnitudes listed, the ratio becomes $10^{-1}\times10^{-3}\times10^{-1}\times1\times1 = 10$. No evidence exists that this approximation to exact similarity limits the atmospheric flows which can be simulated.

Surface Boundary Conditions-The surface roughness conditions are met by scaling roughness elements by the same length scale used for relating the atmospheric- and small-scale flow field provided that the modeled surface will act as an aerodynamically rough surface. Criteria for rough-surface behavior are given in Fig. 5 or an alternative criterion, $u_*h/\nu > 100$, may be used. When the scale reduction is larger, greater than 1:1000, and the surface-roughness elements are small (one story buildings, trees, etc.) the foregoing criterion cannot be met (15). The roughness-element heights in such cases must be exaggerated to regain a rough character. By adding to the scaled roughness height an amount equal to the viscous-zone thickness, $10\nu/u_*$, a surface of appropriate roughness can be obtained.

Surface temperature distributions may be obtained by heating and/or cooling elements in the surface (8, 15). The magnitude of the surface temperature is determined by the requirement to satisfy equality of Richardson numbers for model and atmosphere.

Topographic relief is usually represented by undistorted geometrical scaling of the full-scale features. However, when a large scale reduction is used, exaggeration of the vertical scale may be necessary to preserve similarity of flow over features of significant height. The model study reported in reference (16) required a horizontal scaling of 1:14,000. To attain a roughness Reynolds number of 1200 for Reynolds number independence for flow over features of 500 m elevation difference (an approximate average for the complex mountain topography), a vertical scaling of 1:9600 was used to give an approximate 30% increase in elevation differences.

Approach Flow Characteristics-By using the long test-section wind tunnel shown in Fig. 1, the vertical distribution of mean and fluctuating velocities and temperatures can be simulated very well over a wide range of scales for ground-based thermal stratification which are either stable or unstable over the entire boundary layer (5). When an elevated inversion accompanied by a mixing layer must be simulated in a wind tunnel of the type shown in Fig. 4, a layer of dry ice on a portion of the upstream test-section floor (approximately 7 m) can be used. By varying the length of dry-ice boundary, the downstream surface heating rate and the flow speed, the desired mixing-layer depth H_1 can be obtained. A vertical temperature distribution obtained in this manner immediately upwind of the model of the Yerba Buena Center, San Francisco, shown in Fig. 6 is given by Fig. 7 (17).

Approach-flow characteristics in short to medium length test sections may be controlled to varying degrees by introduction of devices such as jets, vortex generators, grids, roughness plates, screens and heating or cooling elements at the test-section entrance. Although these devices may produce reasonable approach flow characteristics at some distance downstream, in most cases the characteristics vary significantly with distance along the test section. This behavior reduces the usefulness of flows shaped by these techniques for simulation of diffusion in the atmospheric boundary layer. A review of various methods employed is given by Teunissen (18).

RELATIONSHIP OF MODEL SCALE TO SCALES OF ATMOSPHERIC MOTION SIMULATED-Energy spectra for boundary-layer turbulence (Fig. 3) in the meteorological wind tunnel can be compared with the energy spectrum of turbulence in the atmospheric boundary layer given by Van der Hoven (19)

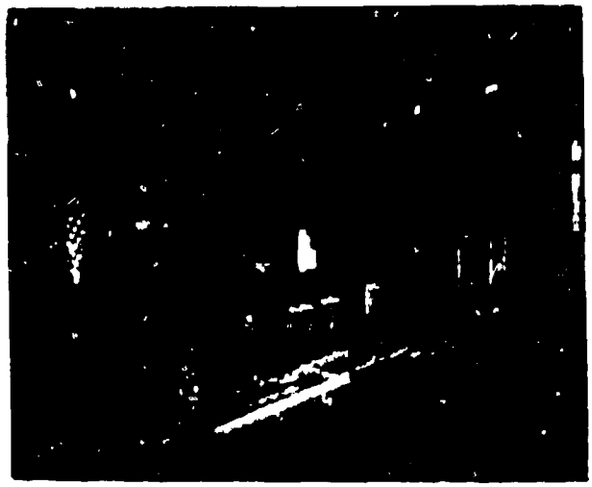


Fig. 6 - Model of Yerba Buena Center, San Francisco (1:240 scale) (17).

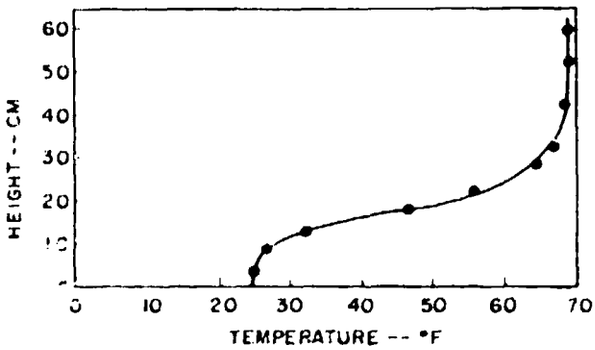


Fig. 7 - Elevated inversion formed in wind tunnel by upstream cooling with dry ice (17).

to establish the scale range of atmospheric motions simulated under neutral and near neutral thermal conditions. Fig. 8 summarizes the simulated spectral ranges for model scales ranging from 10^{-2} to 10^{-4} times the prototype lengths when roughness elements for the full-scale surface have a height $h = 20$ m. The wind-tunnel wave numbers were converted to frequencies for a 6 m/s mean wind speed.

When the length-scale ratio is 10^{-3} nearly all of the scales smaller than the central spectral-gap scale are reproduced. Accordingly, a 1:10,000 scale model represents an optimum scaling for air-pollution studies. Scales down to 1:10,000 can be utilized also but exaggeration of surface roughness becomes necessary for surface roughness elements less than 20 m in height. A scale of 1:10,000 would be used when non-uniformity of mean velocity resulting from topographic features is an important part of the dispersion process. At scales near 1:100 simulation is achieved only down to scales associated with the maximum turbulent energy resulting from local surface roughness. When local diffusion near buildings and building-plume interactions are under investigation, a model scale of approximately 1:100 simulates the important scales of motion.

If short-term pollutant concentrations, say 15-minute average, for a particular mean wind direction and speed are desired, a single set of tracer-gas concentrations can provide the necessary information. However, if long-term averages, say annual averages, are desired, it is necessary to include the effect of large-scale motions not simulated by the model (left of the spectral gap) by making use of mean-wind data provided by the U.S. Weather Service at a nearby established station. In Fig. 8 wind fluctuations at frequencies less than the central spectral-gap frequency can be considered as changes of the mean (1/2-1 hr average) wind. The mean-wind data, obtained over a long period of time, can be used to formulate a probability density distribution for direction and speed of the mean winds. An example of this type of distribution obtained by Davenport (20) for the City of Toronto, Canada, is shown in Fig. 9. This information combined with the modeled concentrations determined as a function of mean wind speed and direction enables long-time averages as well as the occurrence rate for concentrations of a prescribed level to be determined with all scales of motion accounted for (21).

The foregoing discussion pertains to flows in which the primary mode of dispersion is by velocity fluctuations over a wide range of frequencies--turbulence. However, when the flow is near ground level and the topography is complex, the primary mode of dispersion may be advective transport by the mean flow. In this case, the dominant scale of motion is determined by the topographic geometry.

PHYSICAL MODELING OF MASS TRANSPORT

Information of greatest utility in air-pollution investigations is the distribution of pollutant concentrations downwind of a specific source for a range of meteorological conditions of local significance. To obtain this information in the laboratory requires, in addition to construction of a topographic model with local urban features and development of the appropriate approach flow conditions; installation of sources for a tracer gas, sampling of gases over an array of points, analysis of samples for tracer gas concentrations, and measurement of the wind velocities and temperature distribution. The techniques and instrumentation in the wind tunnel will be described.

EXPERIMENTAL TECHNIQUES-Physical modeling of gas transport imposes certain similarity requirements for the source fluid as well as those required for simulation of the natural wind. One of the two most essential similarity parameters is the ratio of emission speed for the source gas to wind speed at the source height V_s/U_s. The other essential parameter has the form of a Froude number for the emitted gas--$\rho_a U_s^2/[(\rho_a-\rho_s)gD]$. An additional consideration is the Reynolds number for source-gas flow through the stack or duct to a vent. The

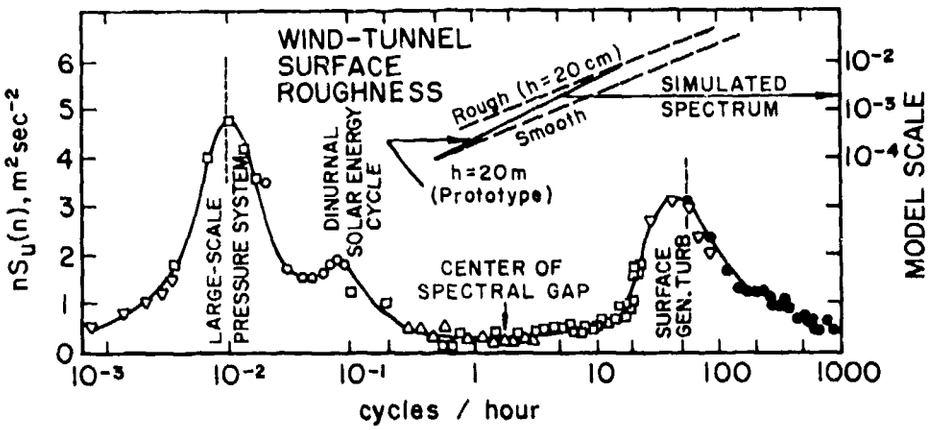


Fig. 8 - Range of simulated scales of atmospheric motion compared with spectrum of Van der Hoven (19) at 100 m.

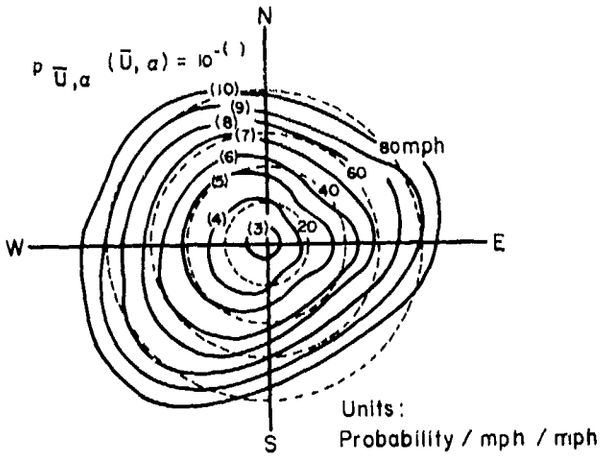


Fig. 9 - Probability density distribution of mean hourly wind speed over downtown Toronto--Davenport (20).

effective Reynolds number for this internal flow should be made as near the prototype value as possible by roughening the internal surface.

The approach flow is ordinarily adjusted to produce a turbulent boundary layer equivalent to a planetary boundary layer at least 400 m thick. In the meteorological wind tunnel shown in Fig. 1, this condition is usually met when the upstream roughness is simulated over a 20-25 m distance upwind of the model. In this facility additional thickening of the boundary layer is achieved by placing an exaggerated roughness over the first 3 or 4 m of the test-section floor. In the shorter environmental wind tunnel (Fig. 4) momentum sinks and vorticity generators are often used to help thicken the boundary layer. The arrangement used to achieve the desired boundary-layer thickness and a comparison with the prototype wind profile for a 1:4000 scale model of Fort Wayne, Indiana (see Fig. 10), is shown in Fig. 11. Vertical temperature distributions can be controlled easily in the meteorological wind tunnel by adjusting the cooling or heating rate of the test-section floor, heating (slightly) the downwind portion and heating the ambient air stream during passage through the ruturn flow section.

When nonuniform surface temperature distribution must be simulated such as for urban heat-islands a grid of nichrome heating wires may be installed in streets of the model. In this manner the temperature distribution for Fort Wayne, Indiana, shown in Fig. 12, was obtained

Once the model is in place, the approach flow is adjusted and the surface boundary condition is established; visual examination of the flow is conducted by releasing smoke (usually titanium dioxide) from source locations of interest. The smoke motion is recorded on motion picture film for early communication with the sponsor and for use in planning the program of concentration measurements.

INSTRUMENTATION - Measuring equipment in addition to the usual hot-wire anemometers, pitot tubes, pressure transducers and thermocouples or resistance thermometers is required for air pollution studies in the laboratory. The specific instrumentation is determined in large measure by the tracer used to determine dispersion characteristics. A variety of tra 's have been used in the Fluid Dynamics and Diffusion Laboratory at Colorado State University. These include ammonia, helium, krypton-85, and hydrocarbons. Concentration measuring systems for the last two tracers will be described briefly.

A typical concentration measuring system for the krypton-85 tracer is shown in Fig. 13. The metered source gas is cooled or heated to arrive in the flow at the temperature and density of the local air stream. Sampling is accomplished by an array of probes which simultaneously draw up to twenty-five samples. Each sample is collected in a glass jar into which it flows as water is displaced from the jar. The sample is then transferred to a lead enclosed chamber containing a stainless steel jacketed Geiger-Mueller tube (Tracerlab TGC-308). Radioactivity levels (tracer concentrations) are determined by reading the G-M tube output on a

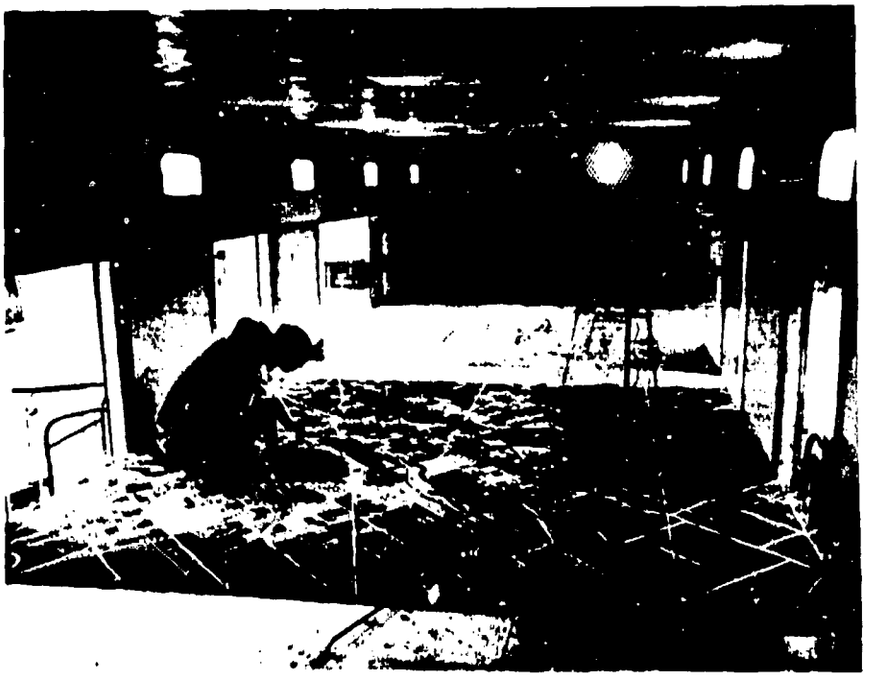


Fig. 10 - Model of Fort Wayne, Indiana (1:4000 scale) (15).

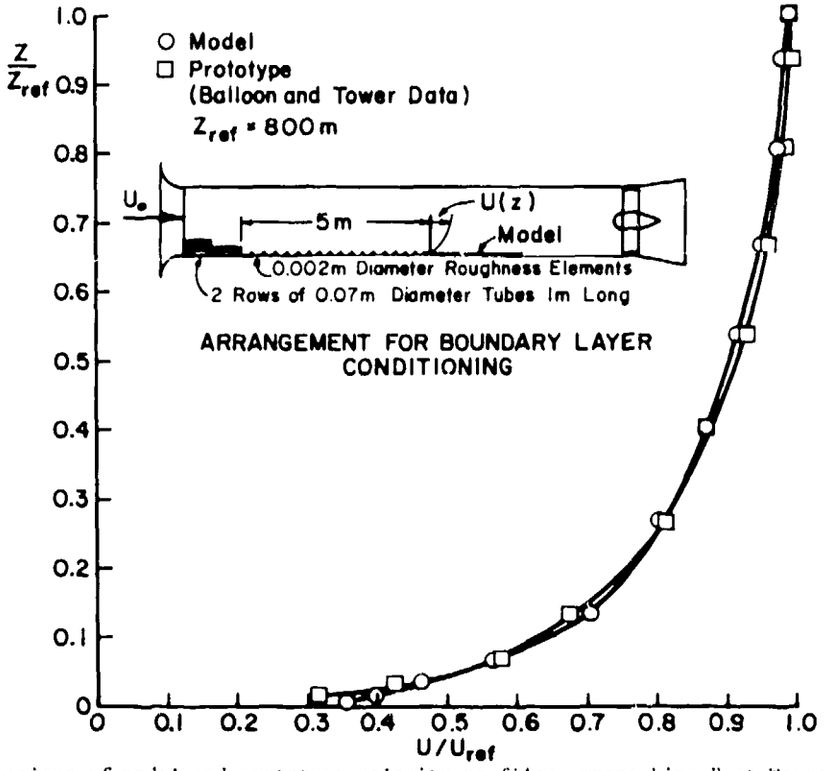


Fig. 11 - Comparison of model and prototype velocity profiles approaching Fort Wayne, Indiana (17).

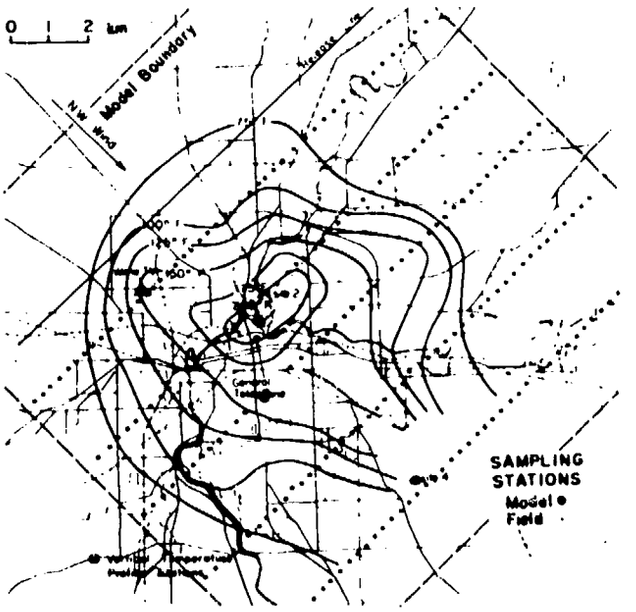


Fig. 12 - "Heat Island" generated over model of Fort Wayne, Indiana (15).

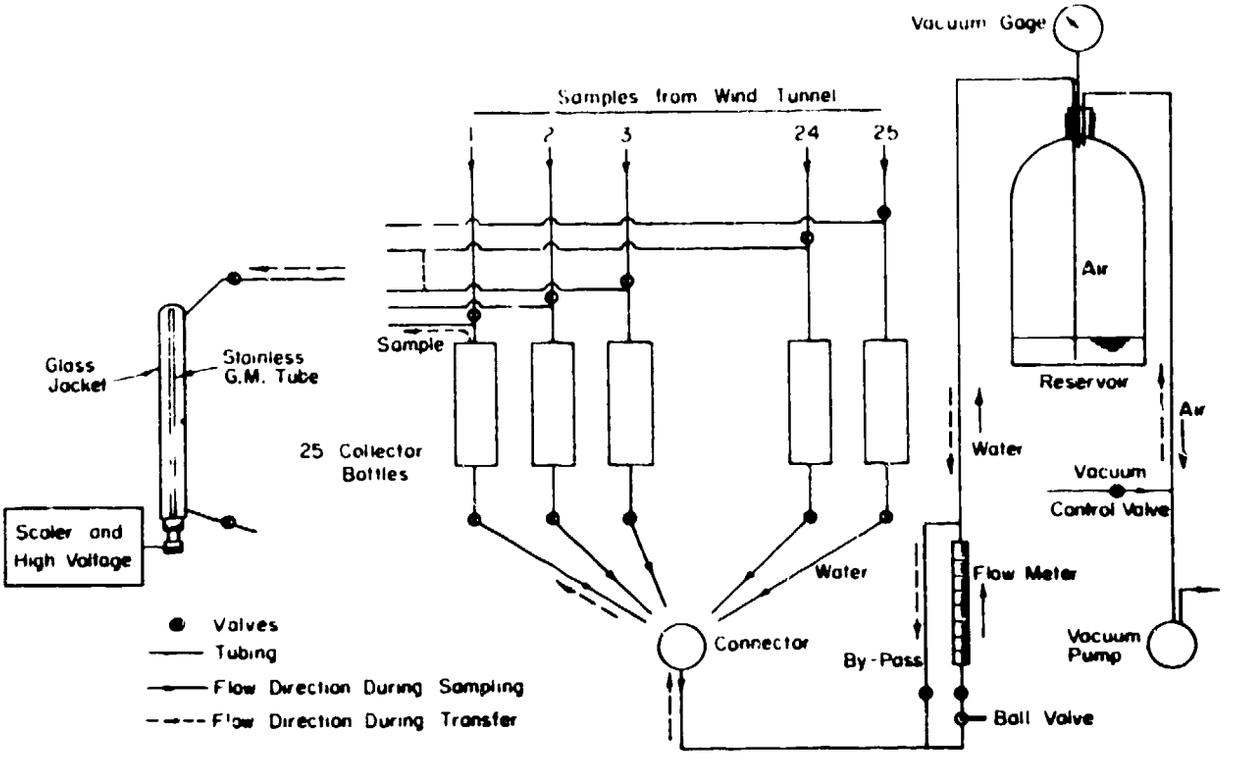


Fig. 13 - Tracer-gas sampling and analysis system (16).

Chicago-Nuclear Ultrascaler (Model 192A). When a hydrocarbon tracer is used the G-M tube is replaced by a Hewlett-Packard Model 5711-A gas chromatograph and the ultrascaler is replaced by a H-P Model 2401C integrating digital voltmeter. An advantage of the hydrocarbon system is that four different hydrocarbons can be used simultaneously to obtain concentrations at a point from each of four sources with one sample. This system is excellent for determination of mean concentrations for steady sources; however, because of the long lines and large volume of sample gas utilized (at least 125 cc) unsteady concentration fields cannot be measured by this method.

COMPARISON OF DATA FROM FULL-SCALE AND PHYSICAL-MODEL MEASUREMENTS

Comparison of concentration data measured in both the atmosphere and the physical model provides the only method for determination of how well the physical model represents the real atmosphere. The inherent difficulties in making comparisons of this type lead to acceptance of the physical model if the two sets of concentrations do not differ by more than the accuracy required for application of the data. Acquisition of a sufficient amount of meteorological and concentration data for a planned confirmation effort has not been accomplished. However, some model studies of diffusion over areas where a few field measurements are available have been made. These are reviewed briefly in the following paragraphs.

Halitsky (22) has conducted a systematic study to confirm scaling criteria for diffusion near a building. Concentration measurements were made on an isolated sharp-edged building 7.0 m high and 9.4 by 12.2 m in plan with a source at the roof center. A 1:300 scale model was used to determine concentration distributions in the laboratory. Halitsky concluded that the isopleth patterns over the building surface will be identical if geometric similarity and dynamic similarity for the effluent and approach flow are satisfied. His measurements also revealed that the Reynolds number for the building should exceed 10^{-4} if the isopleths are to be independent of this parameter.

Diffusion in the atmospheric surface layer and the inner part of the wind-tunnel boundary layer were compared by Cermak (23) using predictions from the Lagrangian similarity hypothesis as a common reference. The rates of decay for maximum ground-level concentrations were in excellent agreement when distances were scaled by the roughness length z_o as predicted by the theory for neutral flow. In these comparisons the wind-tunnel boundary was smooth and the field surface was flat grassland--the roughness lengths gave a scale-length ratio of about 10^{-3}. When the surface layer is thermally stratified the Lagrangian similarity theory predicts that the ratio of z_o to the Monin-Obukhov length $-u_*^3/(\bar{T}$ $gq_o)$ must be equal for the model and atmosph . (a condition which is an alternative expression of the Richardson number requirement), Chaudhry (24) compared diffusion in a stably stratified wind-tunnel boundary layer with atmospheric data and concluded that the parameters evaluated for field data by Klug (25) hold for the wind-tunnel data.

The study of diffusion over a 1:4000 scale model of Fort Wayne, Indiana, (Fig. 10) reported by Chaudhry and Cermak (15) provided concentration data for comparison with data from the field study (26). The vertical scale was doubled (1:2000) to retain an aerodynamically rough surface and the urban heat island was simulated by surface heating as shown in Fig. 12. Zinc-sulfide particles were used as a tracer in the field and krypton-85 was used as the laboratory tracer. The difference in aerodynamic behavior of the two tracers caused differences in the diffusion characteristics over the first 3,000 m downwind of the elevated line source. However, between 3,000 m to 12,000 m similar diffusion characteristics were found--the decay rate for ground-level concentrations was in agreement and the growth rate for plume height was equal. When the surface-dosage distributions were averaged for the 70 field realizations (Fig. 14), agreement was found with gross features of the simulated distributions near the central part of the city shown in Fig 15.

Comparison of concentrations measured over a 1:9600 scale model of the Climax, Colorado, area in the Rocky Mountains was made with several field measurements at the same site (27). The flow was stably stratified to simulate winter storms. At a distance 19.2 km downstream from the source, the nondimensional concentration coefficient $\chi U_o/Q_o$ ranged from 15×10^{-9} to 18×10^{-9} for the model and from 1×10^{-9} to 68×10^{-9} for field values at contiguous points. The close agreement of these data give strong support for atmospheric simulation on this scale.

EXAMPLE APPLICATIONS OF PHYSICAL MODELING

Physical modeling of natural wind and wind effects is used extensively to obtain data for both specific applications and systematic parameter investigations. The most common and generally accepted usage is in determination of wind forces on structures and concentrations of gaseous materials released into the atmosphere (6, 28). Several examples follow to illustrate applications to investigation of air-pollutant dispersion.

DISPERSION IN LOCALITY OF PROPOSED URBAN DEVELOPMENT-Parking garages in urban centers result in large sources of carbon monoxide, nitrogen oxides and hydrocarbons. Concentrations resulting from the underground parking garage for the proposed Yerba Buena Center beneath the low building (center foreground) of Fig. 7 were determined by physical modeling (17). In this development the garage ventilation system will discharge gases into the atmosphere through eight stacks located in the arena and central plazas. Based upon aesthetic considerations, the best-stack criterion for a specific power usage by the ventilation system is the shortest stack possible that will not result in unacceptable environmental impact for the center. Fig. 16 and 17 give typical concentration distributions for emissions from two stacks in a west wind. Similar sets of data for a variety of wind direction

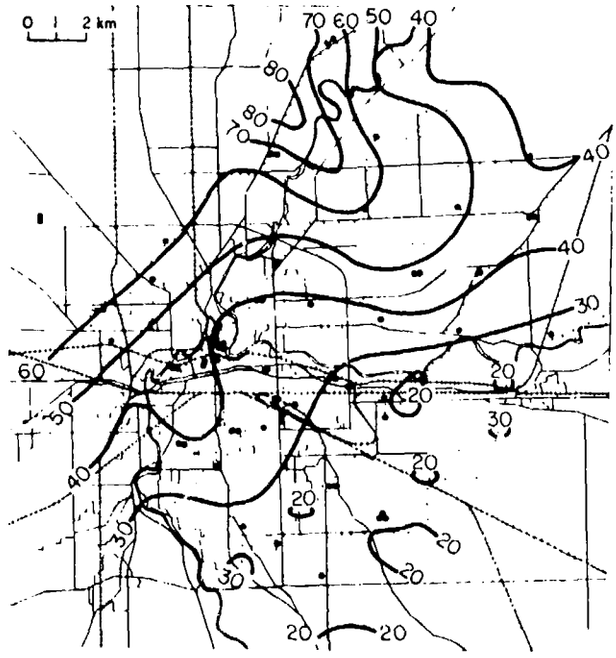


Fig. 14 - Average surface dosage observed over Fort Wayne, Indiana--average of 70 realizations (26).

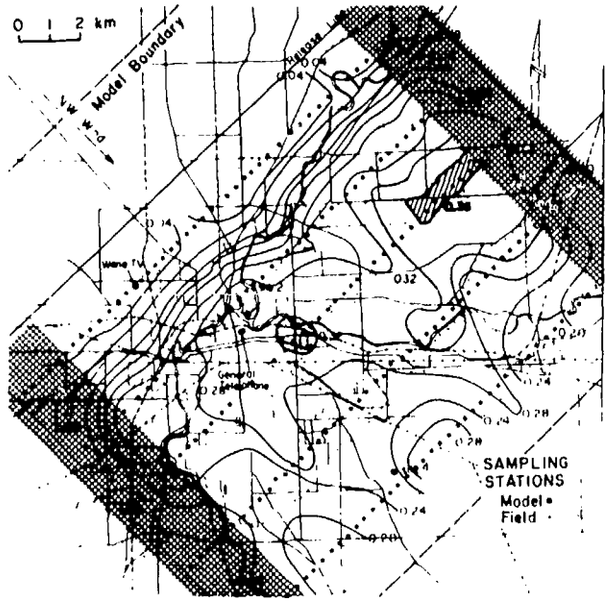


Fig. 15 - Surface dosage pattern observed over 1:4000 scale model of Fort Wayne, Indiana.

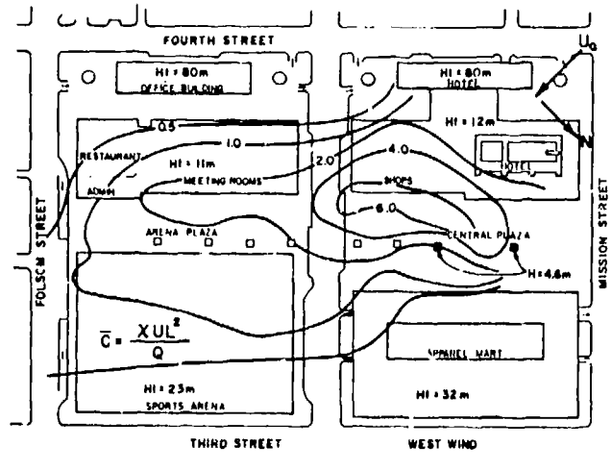


Fig. 16 - Concentration coefficients for dispersion of underground parking garage exhausts by two short (4.6 m) stacks in Yerba Buena Center Center (1:240 scale model) for west wind.

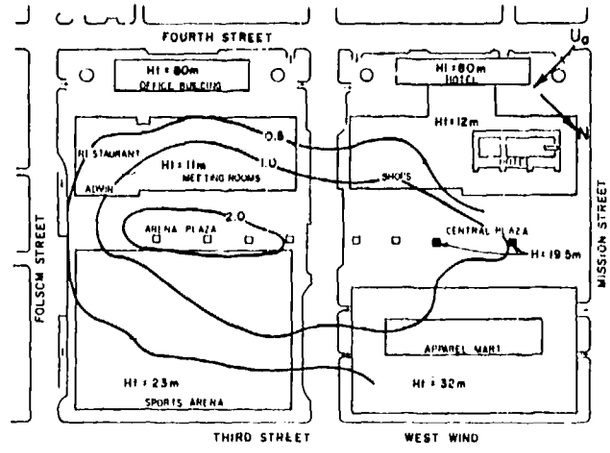


Fig. 17 - Concentration coefficient for dispersion of underground parking garage exhausts by two extended (19.5 m stacks in Yerba Buena Center (1:240 scale model) for a west wind.

and stack heights provided adequate information to complete an environmental impact statement and reach an decision on the stack height.

EFFECT OF GEOMETRY ON DISPERSION IN AN IDEALIZED CITY-An idealized city composed of uniform blocks shown in Fig. 18 was used to obtain a set of reference dispersion data for exhaust gases emitted by two lanes of traffic (29, 30, 31). The model consisted of uniform blocks 0.2 m square by 0.05 m high separated by straight streets 0.0008 m wide. Blocks covered the wind-tunnel floor for a distance of 9.5 m in the flow direction over the 3.7 m width of the test section. Geometrical modifications to blocks surrounding the line sources are defined by Fig. 19.

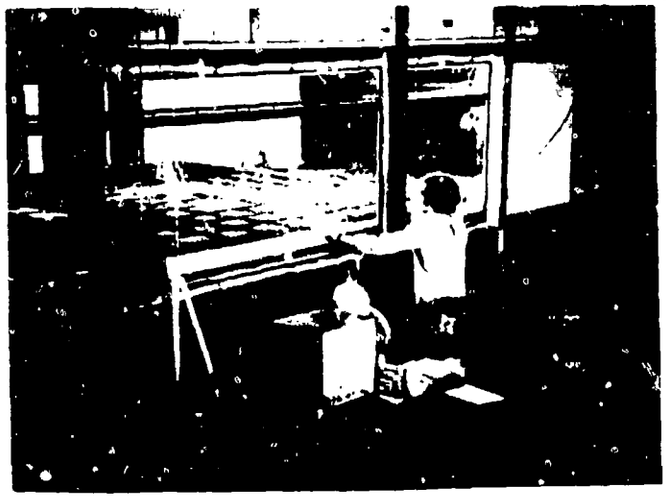


Fig. 18 - Model of idealized city in environmental wind tunnel (Fig. 4)--approximately 1:400 scale.

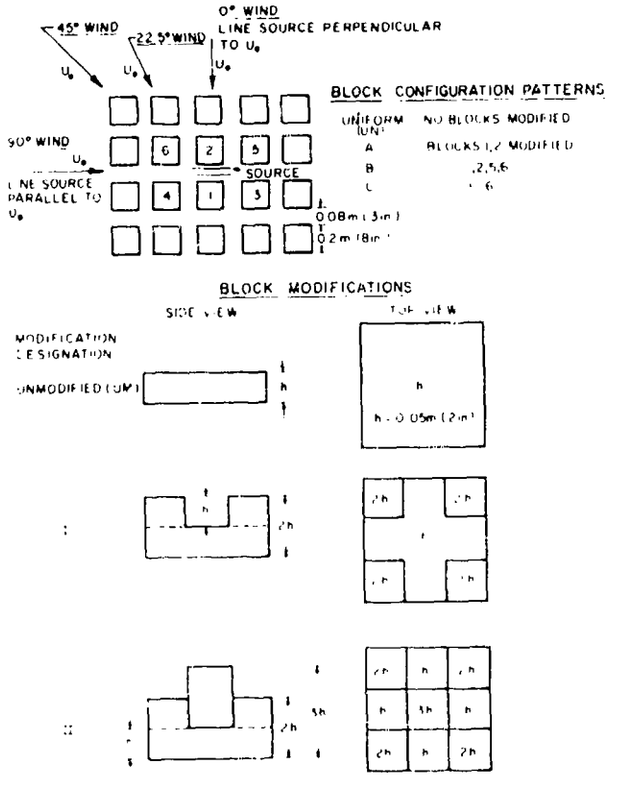


Fig. 19 - City block geometry and test configurations for 1:400 scale idealized urban center.

The mean concentrations may be averaged over a surface to obtain a relative measure for comparing overall dispersion efficiency in the street canyon for different configurations of wind direction and block geometry. A listing of this type of coefficient $\bar{C}$ is given in Table 1 for the upwind and downwind faces of the canyon. The trends are not simple. A uniform array of solid blocks (UN - UM) is least efficient and the arrangement A-1 the most efficient for most cases. Since configuration A-1 constitutes the least modification of the uniform block array, these results indicate isolated higher building elements effectively reduced exhaust concentration in city streets. If the higher building elements become more densely packed such as for configuration C-II the average concentrations tend to rise.

Average mean-concentrations were also determined on streets for a range of downwind distance x from the source for urban configurations shown by Table 2. Table 2 gives some of these values for the 0° wind. The value of $\bar{C}$ is proportional to $x^{-0.65}$ for the uniform block array. The decay rate is approximately x^{-1} for a 90° wind and $x^{-1.25}$ for a 45° wind. Accordingly, wind direction is a strong factor in the determination of dispersion rates for street-level sources.

Data sets corresponding to systematic configuration variations indicated in Fig. 19 for a "one-block" source can be used to predict concentrations for all blocks involved in the proposed traffic plan.

Table 1 Average Mean-Concentration Coefficients, $\bar{C}$ on Building Faces Adjacent to Source

CONFIGURATION	$\bar{C}$ DOWNWIND FACE	$\bar{C}$ UPWIND FACE
0° - UN - UM	4.21	13.08
0° - A - I	1.31	7.08
0° - B - I	1.87	6.46
0° - C - I	0.85	8.21
0° - A - II	1.40	8.32
0° - B - II	1.37	7.40
0° - C - II	1.35	7.91
45° - UN - UM	2.02	8.54
45° - A - I	1.05	4.95
45° - B - I	1.48	9.52
45° - C - I	1.94	7.68
45° - A - II	0.90	3.60
45° - B - II	3.02	4.81
45° - C - II	1.36	6.45
90° - UN - UM	3.54	3.42
90° - A - I	0.48	0.60
90° - B - I	0.52	3.65
90° - C - I	1.65	3.92
90° - A - II	0.50	0.55
90° - B - II	0.90	2.78
90° - C - II	4.23	3.19

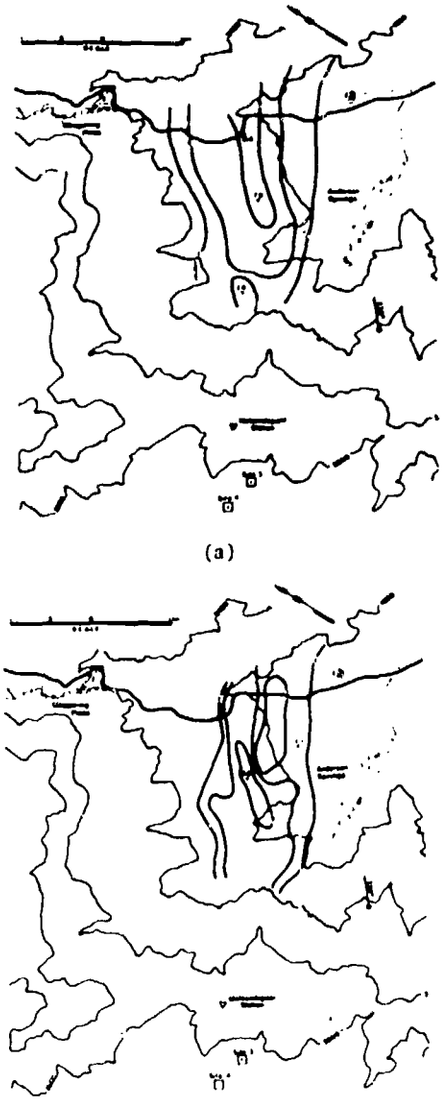
Table 2. Average Mean-Concentration Coefficients $\bar{C}$ at Street Level for Streets Downwind from Source

CONFIGURATION	NO. OF STREETS DOWNWIND OF SOURCE	$\bar{C}$ STREET LEVEL
0° - UN - UM	1	0.47
	2	0.30
	3	0.25
	4	0.20
	5	0.20
	6	0.14
	7	0.14
0° - C - I	2	0.20
	4	0.10
	6	0.08
0° - C - II	2	0.09
	4	0.05
	6	0.05

DISPERSION OVER A COMPLEX TERRAIN-Numerous investigations of the atmospheric boundary-layer dispersion characteristics for complex surface geometries have been conducted at the Colorado State University Fluid Dynamics and Diffusion Laboratory (32, 33, 34). The application of the wind-tunnel investigations has ranged from planning orographic cloud-seeding strategies (27, 35) to urban air-pollution assessment (29). However, most applications have involved determination of concentrations resulting from power-plant emissions (36-39). An example of such an investigation is provided by a study in the environmental wind tunnel (Fig. 4) of H_2S dispersion from cooling towers positioned in an area of the The Geysers geothermal area about 130 km north of San Francisco, shown in Fig. 20. Due to complexity of the terrain, standard diffusion estimates are of uncertain accuracy; hence, physical modeling was undertaken to evaluate the environmental impact under neutral stratification on surrounding populated areas.

Fig. 20 - Model of the Geyser Field, Northern California, in environmental wind tunnel, FDDL, 1:1920 scale.

A total of nine existing or potential geothermal power-plant sites were tested over a range of wind directions and speeds (3-13 m/s). Fig. 21 reveals the effect of wind speed on ground-level concentrations for a particular plant site, wind direction and plant operating level.



(a)

(b)

Fig. 21 - Isopleths (x 10^5) of nondimensional concentration coefficient $\bar{C}$ for Site 3, a 230° wind direction and wind speeds of (a) 4.5 and (b) 11.6 m/s.

SUMMARY

Motion in the atmospheric boundary layer can be simulated with such accuracy by meteorological wind tunnels that physical modeling of air-pollutant dispersion can be used to obtain reliable predictions of pollutant concentrations. In particular, when local boundary geometry is complicated by groups of buildings or complex topography, physical modeling becomes an indespensable tool for predicting dispersion over short distances. Satisfactory agreement between characteristics in the simulated and real atmosphere has been found whenever field data have been available for making comparisons.

NOMENCLATURE

$\bar{C}$ = a mean concentration coefficient

$\underline{\bar{C}}$ = space averaged mean concentration coefficient

C_p = specific heat at constant pressure, L^2/t^2T

$f(K)$ = energy spectrum of longitudinal fluctuations, L

g = gravitational acceleration, L/t^2

h = roughness-element height, L

H_I = height of inversion, L

k = thermal conductivity of fluid, ML/t^3T

k_c = diffusivity of contaminant in air, L^2/t

K_M = eddy diffusivity for momentum, L^2/t

K_s = equivalent sand roughness, L

L = reference length, L

n = frequency, t^{-1}

P = deviation of mean pressure from static reference, ML/t^2

q_o = surface heat flux, M/t^3

Q = source strength, M/t

$S_u(n)$ = energy spectrum of longitudinal velocity fluctuations, L/t

t = time, t

T = instantaneous temperature, T

T_w = mean temperature at $z = 0$, T

$\Delta\bar{T}$ = $\bar{T} - \bar{T}_w$, T

$(\Delta\bar{T})_o$ = $\bar{T}_o - \bar{T}_w$, T

u_i = ith component of instantaneous velocity, L/t

U_i = ith component of mean velocity, L/t

V_s = exit speed of source gas, L/t

w' = vertical velocity fluctuation, L/t

x_i = ith space coordinate, L

z = vertical coordinate, L

z_o = roughness length, L

α = wind azimuth

δ = boundary-layer thickness, L

δ_T = thermal boundary-layer thickness, L

δ_{ij} = Kronecker delta

ε = energy dissipation rate per unit of mass, L^2/t^3

ε_{ijk} = permutation tensor

ρ = mass density, M/L^3

ν = kinematic viscosity, L^2/t

τ_o = surface shear stress, ML/t^2

ϕ = dissipation function, M/Lt^3

χ = mean concentration, M/L^3

Ω = angular velocity, t^{-1}

Subscripts:

$( )_o$ = reference quantity

$( )_s$ = quantity at source

Superscripts:

$( )^*$ = nondimensional quantity

$(\bar{\ })$ = time average

$( )'$ = instantaneous fluctuation from time average

Dimensions:

L -- length

M -- mass

t -- time

T -- temperature

ACKNOWLEDGEMENTS

Support for the preparation of this paper was provided in part by National Service Foundation Grant ENG 76-03135 awarded to Colorado State University for research on Wind Effects on Buildings, Structures and Urban Areas.

REFERENCES

1. Pasquill, F., "Atmospheric Diffusion," Second Edition, John Wiley and Sons, New York, 1974.

2. Monin, A. S. and Yaglom, A. M., "Statistical Fluid Mechanics, Mechanics of Turbulence," The MIT Press, 1971.

3. Lumley, J. L. and Panofsky, H. A., "The Structure of Atmospheric Turbulence," Interscience Publishers, 1964.

4. Hidy, G. M., "Adventures in Atmospheric Simulation," Bulletin of the American Meteorological Society, Vol. 48, No. 3, March, 1967, pp. 143-161.

5. Cermak, J. E., "Laboratory Simulation of the Atmospheric Boundary Layer," AIAA Journal, Vol. 9, No. 9, September, 1971, pp. 1746-1754.

6. Cermak, J. E., "Application of Fluid Mechanics to Wind Engineering--A Freeman Scholar Lecture," Transactions, American Society of Mechanical Engineers, Journal of Fluids Engineering, Vol. 97, March, 1975, pp. 9-38.

7. Ruark, A. E., "Inspection Analysis: A Method Which Supplements Dimensional Analysis," Journal Elisha Mitchell Sci. Soc. Vol. 51, 1935, pp. 127-133.

8. Cermak, J. E., "Wind Tunnel for the Study of Turbulence in the Atmospheric Surface Layer," Technical Report CER58JEC42, Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, 1958.

9. Plate, E. J. and Cermak, J. E., "Micrometeorological Wind-Tunnel Facility," Technical Report CER65EJP-JEC9, Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, 1963.

10. Zoric, D. and Sandborn, V. A., "Similarity of Large Reynolds Number Boundary Layers," Journal of Boundary Layer Meteorology, Vol. 2, No. 3, March 1972.

11. Cermak, J. E., Sandborn, V. A., Plate, E. J., Binder, G. H., Chuang, H., Meroney, R. N. and Ito, S., "Simulation of Atmospheric Motion by Wind-Tunnel Flows," Technical Report CER66JEC-S117, Fluid Mechanics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, 1966.

12. Cermak, J. E., "Laboratory Simulation of Atmospheric Motion in the Lowest One Hundred Meters," Proceedings of Meeting on Ground Wind Load Problems in Relation to Launch Vehicles, Langley Research Center, Hampton, Virginia, January, 1966.

13. Pond, S., Stewart, R. W. and Burling, R. W., "Turbulence Spectra in Wind Over Waves," Journal of Atmospheric Science, Vol. 20, 1963.

14. Schlichting, H., "Boundary Layer Theory", McGraw-Hill Book Company, Inc., 1960.

15. Chaudhry, F. H. and Cermak, J. E., "Wind-Tunnel Modelling of Flow and Diffusion Over an Urban Complex," Technical Report CER70-71FHC-JEC24, (Project THEMIS Report No. 17), Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, May, 1971.

16. Orgill, M. M., Cermak, J. E. and Grant, L. O., "Laboratory Simulation and Field Estimates of Atmospheric Transport--Dispersion Over Mountainous Terrain," Technical Report CER70-71MMO-JEC-LOG40, Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, May, 1971.

17. Cermak, J. E., Chaudhry, F. H., Hansen, A. C. and Garrison, J. A., "Wind and Air-Pollution-Control Study of Yerba Buena Center," Technical Report CER71-72JEC-FHC-ACH-JAG15, Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, 1972.

18. Teunissen, H. W., "Simulation of the Planetary Boundary Layer in a Multiple-Jet Wind Tunnel," Institute for Aerospace Studies, Report 182, University of Toronto, Toronto, Canada, 1972.

19. Van der Hoven, I., "Power Spectrum of Horizontal Wind Speed in the Frequency Range from 0.0007 to 900 Cycles Per Hour," Journal of Meteorology, Vol. 14, 1957.

20. Davenport, A. G., "On the Statistical Prediction of Structural Performance in the Wind Environment," Meeting Preprint 1420, ASCE, National Structural Engineering Meeting, Baltimore, Maryland, 1971.

21. Cermak, J. E., "Wind Effects on Buildings and Structures," Paper presented at Institute on Application of Stochastic Methods, Colorado State University, Fort Collins, Colorado, August, 1972.

22. Halitsky, J., "Validation of Scaling Procedures for Wind-Tunnel Model Testing of Diffusion Near Building," Geophysical Sciences Laboratory, Report No. TR-69-8, Department of Meteorology, New York University, New York, NY, 1969.

23. Cermak, J. E., "Lagrangian Similarity Hypothesis Applied to Diffusion in Turbulent Shear Flow," Journal of Fluid Mechanics, Vol. 15, Part 1, 1963.

24. Chaudhry, F. H., "Turbulent Diffusion in a Stably Stratified Shear Layer," Ph.D. Dissertation, Colorado State University, Fort Collins, Colorado, 1969.

25. Klug, W., "Diffusion in the Atmospheric Surface Layer: Comparison of Similarity Theory with Observations," Quarterly Journal of the Royal Meteorological Society, Vol. 94, 1968.

26. Hilst, G. R. and Bowne, N. E., "A Study of the Diffusion of Aerosols Released from Aerial Line Sources Upwind of an Urban Complex," Final Report Contract No. DA42-007-AMC-38(R), The Travelers Research Center, Inc. Hartford, Connecticut, 1966.

27. Cermak, J. E., Orgill, M. M. and Grant, L. O., "Laboratory Simulation of Atmospheric Motion and Transport Over Complex Topography as Related to Cloud-Seeding Operation," Proceedings of Second National Conference on Weather Modification, Santa Barbara, California, April, 1970.

28. Cermak, J. E., "Wind-Tunnel Testing of Structures," Journal of the Engineering Mechanics Division, ASCE, Vol. 103, No. EM6, December 1977, pp. 1125-1140.

29. Cermak, J. E. and Thompson, R. S., "Urban Planning," Chapter 13 in Lead in the Environment, NSF Report NSF/RA-770214, U.S. Government Printing Office, Washington, D. C., 1973, pp. 229-239.

30. Lombardi, D. J., "Steady State Pollutant Concentrations in Urban Areas," M.S. Thesis, Fluid Mechanics and Wind Engineering Program, Colorado State University, Fort Collins, Colorado, 1978, pp. 110.

31. Wedding, J. B., Lombardi, D. J. and Cermak, J. E., "A Wind-Tunnel Study of Gaseous Pollutants in City Street Canyons," APCA Journal, Vol. 27, No. 6, June, 1977, pp. 557-566.

32. Cermak, J. E. and Peterka, J., "Simulation of Wind Field over Point Arguello, California, by Wind-Tunnel Flow over a Topographic Model," Technical Report CER65JEC-JAP64, Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, 1966.

33. Lin, J. T. and Binder, G. J., "Simulation of Mountain Lee Waves in a Wind Tunnel," Technical Report No. CER67-68 JTL-GJB24, Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, December, 1967.

34. Kitabayshi, K. K., Orgill, M. M. and J. E. Cermak, "Laboratory Simulation of Air Flow in Atmospheric Transport-Dispersion over Elk Mountain, Wyoming," Technical Report CER-70-71KKK-MMO-JEC65, for Atmospheric Water Resources Research Division, U.S. Bureau of Reclamation, Fluid Dymanics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, July, 1971.

35. Orgill, M. M., Cermak, J. E. and Grant, L. O., "Laboratory Simulation and Field Estimate of Atmospheric Transport-Dispersion over Mountainous Terrain," Technical Report CER70-71MMO-JEC-LOG40 for Atmospheric Water Resources Research Division, U.S. Bureau of Reclamation, Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, May, 1971.

36. Cermak, J. E. and Mutter, D. G., "Physical Modeling of Atmospheric Transport of Stack Emissions at Kahe Electrical Generating Plant Oahu, Hawaii," Technical Report CER77-78JEC-DGM28, (Vol. 1, 2, 3) for Stearns-Roger, Inc., Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, April, 1978.

37. Petersen, R. L., Cermak, J. E. and Ayad, S. "Atmospheric Transport of Hydrogen Sulfide from Proposed Geothermal Power Plant (Unit 13)--Predictions by Physical Modeling in a Wind Tunnel," Technical Report CER76-77RLP-JEC-SA51 for Aminoil USA, Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, April, 1977.

38. Cermak, J. E. and Petersen, R. L., "Atmospheric Transport of Hydrogen Sulfide from Proposed Geothermal Power Plant (Unit 16)," Technical Report CER76-77JEC-RLP43 for Pacific Gas and Electric Company, Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, March 1977.

39. Petersen, R. L. and Cermak, J. E., "Atmospheric Transport of Hydrogen Sulfide from Proposed Geothermal Power Plants (Units 13, 14, 16 and 18), for the West Wind Direction," Technical Report CER77-78RLP-JEC10 for the Pacific Gas and Electric Company, Fluid Dynamics and Diffusion Labortory, Colorado State University, Fort Collins, Colorado, November, 1977.

DISCUSSION

PASQUILL: You remember this morning we were talking about the Deardorff similarity and its possible applicability in the wind conditions of the atmosphere. I am talking of his laboratory similarity model Do you see any prospects of being able to test the applicability of that sort of modeling which is in his case verified from a still tank? Do you see any prospects of testing the applicability of that in a flow as you have in your wind tunnel with the unstably stratified conditions?

CERMAK: What tank was that again?

PASQUILL: Deardorff's was a water tank with the surface heated. One of the problems is what is the range of applicability in the atmosphere, up to what wind speed will those same laws apply in the boundary layer of the atmosphere?

CERMAK: Well, the last part of your question, I think, is extremely important and I recall that some of the work that Dr. Townsend did on unstably stratified flows, in very weak convective systems, showed that very weak convection really organizes the flow very much and changes the pattern of the flow. I think that a small wind field convection will change considerably the kind of results that Jim Deardorff got in his channel without any forced convection at all. This is work that needs to be continued. There is evidence already on the record from Townsend's work that there is quite a gross change in the flow characteristics, when you just put a weak shear on it.

Furthermore in our laboratory we are now looking at the case of drainage flows that are created by just cooling a surface without any forced convection on it. This is a frontier area, too, that needs to be developed by further research, in order to complete the spectrum of what needs to be looked at from the standpoint of the atmosphere.

CO IMPACT OF GENERAL AVIATION AIRCRAFT

George J. Schewe[†]
Laurence J. Budney[†]
Bruce C. Jordan

U. S. Environmental Protection Agency

[†] On assignment from the National Oceanic and Atmospheric Administration
U. S. Department of Commerce

ABSTRACT

A modeling analysis of the impact of general aviation aircraft on ambient carbon monoxide (CO) concentrations was conducted, using EPA's PAL (Point-Area-Line) dispersion model. The analysis focuses on single and twin piston-engine aircraft at Van Nuys airport in California--the busiest general aviation airport in the U. S. Emissions are estimated from AP-42 for various aircraft engine types and characteristic emission factors, modes of operation, and aircraft traffic density. Sources modeled included taxiways, taxiway queues, runways, approach and climbout paths to 900 meters above ground level, aircraft parking area, and engine run-up areas. The meteorological input is chosen to represent realistic worst case (high CO impact) conditions occurring at the airport. Results indicate violations of the 1 and 8-hour National Ambient Air Quality Standards for CO at receptor locations within 100 meters of some of the emission sources. Concentrations decrease rapidly with downwind distance, so that maximum CO impacts beyond about 200 meters are well below the air quality standards.

A DISPERSION MODELING ANALYSIS was conducted to estimate the impact of general aviation aircraft on ambient CO concentrations. The analysis focuses on Van Nuys Airport in California, which is the busiest general aviation airport in the U. S. The scope of the analysis is confined to single and twin piston-engine aircraft, accounting for 93 percent of aircraft operations at the airport. Other CO sources and background concentrations are not taken into account. Concentration estimates are made near the runways and aircraft parking lots and out to the point where CO concentrations are less than approximately 2-3 mg/m^3.

MODEL APPLICATION

The PAL (Point-Area-Line Source) dispersion model (1)* is used to estimate the CO concentrations. The model is a method of estimating short term dispersion using Gaussian-plume steady-state assumptions for any concentration averaging time from 1 to 24 hours. Calculations are performed for each hour. Hourly meteorological input including wind speed, wind direction, stability class, and mixing height is specified. The model handles emissions from a limited number of point, area and line sources (up to 30 of each type).

In this study, estimated aircraft emissions data are based upon characteristic aircraft engine emission factors, modes of operation, and aircraft traffic density. Traffic densities are based upon hourly tabulations of traffic during a full month of busy operation at Van Nuys. Heaviest aircraft traffic occurs from about 9:00 A.M. until sunset; hence, emissions and meteorological data from that time of day are used in the model to estimate maximum ambient concentrations. Emissions estimates are discussed further under Source Data.

Given the fact that most of the CO emissions attributed to aircraft are near ground-level, the highest ambient ground-level concentrations are expected to occur during stable atmospheric condition with low wind speeds. Three years of hourly meteorological data from a nearby station (at Burbank) show that stable conditions are a common occurrence at Van Nuys. However, during the heavy aircraft traffic period, stable conditions occur only in the hour immediately preceding sunset. Thus, stable atmospheric conditions (Pasquill Stability E) and a wind speed of 2 mps is assumed as the worst case meteorological condition in the computation of maximum 1-hour concentrations.

These conditions are not appropriate for making 8-hour estimates, however. To estimate the highest 8-hour concentrations, wind direction persistence becomes a critical factor. Analysis of the Burbank meteorological data indicates that the highest eight-hour concentrations probably occur when (1) the wind direction is constant during the last four hours of the busy traffic period, (2) atmospheric conditions are stable during the last hour, and (3) wind speeds are somewhat higher than in the case of maximum 1-hour concentrations. Based on that analysis, the following is assumed in estimating the highest 8-hour concentrations:

- 4 hours of zero CO impact (due to variable winds and vigorous mixing which leads to good dispersion);
- 3 hours of D (neutral) stability and a wind speed of 4 mps;
- 1 hour of E stability and a wind speed of 3 mps.

*Numbers in parenthesis designate References at end of paper.

SOURCE DATA

General aviation aircraft at Van Nuys Airport are generally characterized by single or twin piston engines. In order to make reasonable estimates of the emissions, several alternative engines used in the aircraft classifications must be considered. To estimate the distribution of engines used, the national mix of single and twin engine types is assumed for this analysis. Using this distribution as the weighting factor and recent emission factors which will supplement AP-42, (2),(3), two composite emission factors for single engine and twin engine general aviation aircraft are derived. These composite emission factors are further differentiated according to mode of operation and source types as discussed in the following sections.

Because aircraft emissions at an airport can be attributed to several travel modes, and because the PAL model can distinguish between several kinds of sources, up to 30 of each per run, the CO emissions from general aviation aircraft at Van Nuys are modeled by allocating them over several representative sources. These sources include:

Straight-line Sources--
- Taxiways
- Taxiway Queues
- Runways (Takeoff and Rollout)
- Approach and Climbout Paths

Area Sources--
- Aircraft Parking Areas
- Run-up Areas*

The distribution of assumed ground-level sources is indicated in Figure 1. The assumed approach and climbout paths are shown in Figure 2. Runway lengths, rollout, takeoff, climbout and approach lengths are representative of typical landing and takeoff cycles for single and twin engine aircraft(4). The 900 m ceiling represents the approximate height above which CO emissions from the aircraft have insignificant impact on the ground level receptors. The estimated travel distances are used with the average aircraft speeds in each mode to estimate the time spent in each mode.

The assumed distribution of taxiways is a simplification of the taxiway network at Van Nuys Airport. Only the taxiways with the most frequent use are accounted for. Although the taxiway queues are always assumed to terminate at the end (North coordinate) of the respective taxiway, the length of these queues varies as a function of traffic density (aircraft operations per hour). Thus, taxiway queues are not shown in Figure 1. Parking lot emission rates are assumed to be primarily a function of the size of the parking lots and thus aircraft are prorated accordingly to each parking area. The run-up areas are approximated by very small area sources to emphasize their point-like nature. Emissions are estimated by assuming the emissions that occur at takeoff, which is a similar full thrust situation.

*Run-up areas, located near one end of each runway, are for the purpose of engine run-up prior to takeoff.

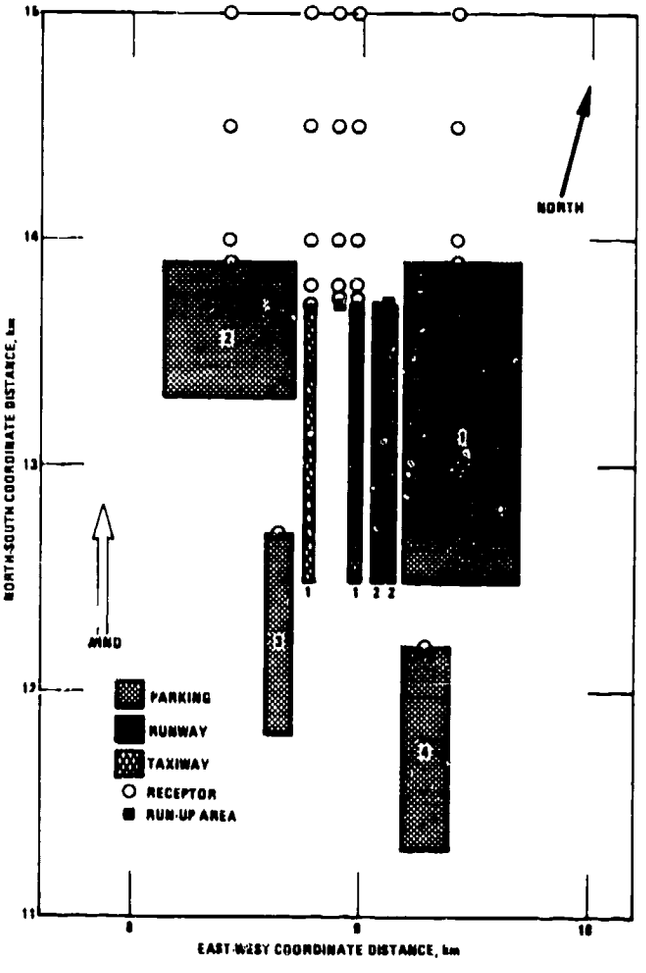


Fig. 1 - Plan view of the assumed distribution of ground-level sources at Van Nuys Airport

The estimated emissions from each of the above-mentioned sources are a function of (1) aircraft engine emission factors, (2) weighting factors based upon the distribution of various aircraft types, (3) modes of operation, (4) time (or distance travelled) by aircraft in each mode, and (5) aircraft traffic densities. The noncontinuous nature of the emissions from each source is treated by averaging the emissions per aircraft over the desired time frame (averaging time of the estimated concentrations). The total hourly emissions are determined by combining the composite emission factors discussed above with the traffic density

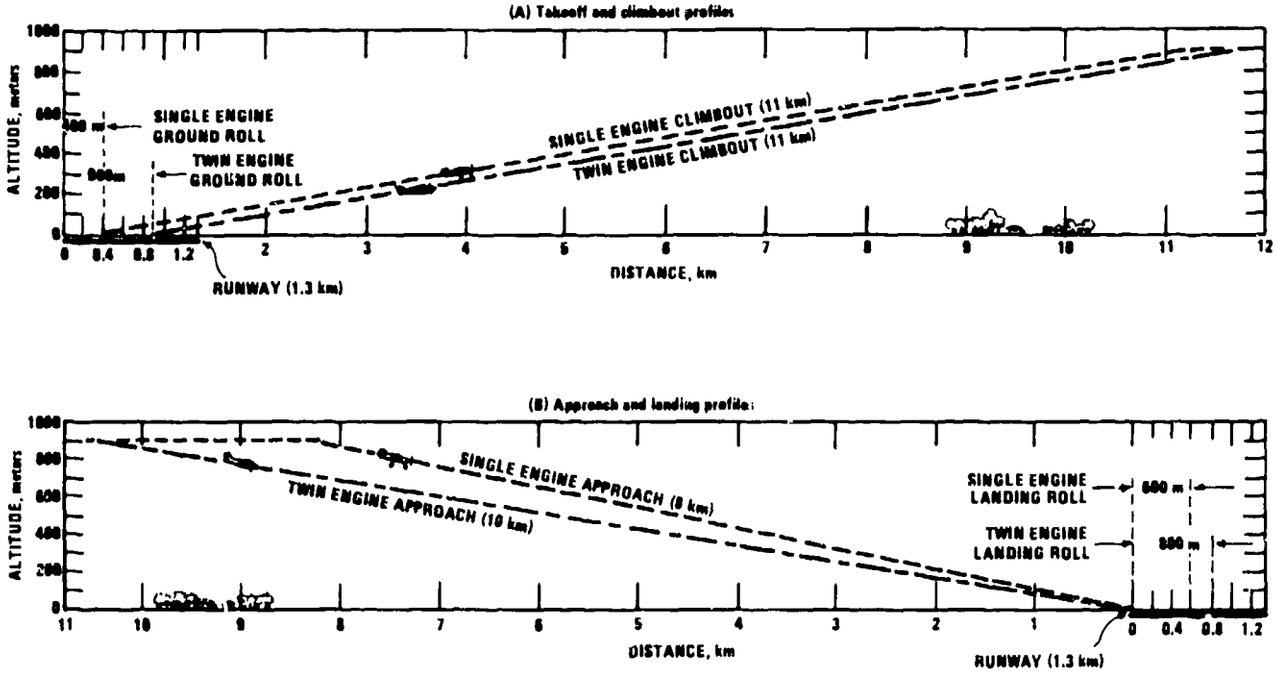


Fig. 2 Diagram of assumed approach, landing, takeoff, and climbout profiles for single and twin engine aircraft

per hour to generate emissions estimates per mode per source. For computation purposes and to characterize average worst case traffic at Van Nuys, the number of landing and take-off operations is assumed equal during any given hour of analysis.

Given the above assumptions and calculation procedures, two variations of the emission configuration are studied for the one-hour estimates. In the first, all aircraft use the main runway at Van Nuys. The second configuration assumes that 35 percent of the single engine aircraft use a second runway and taxiway, parallel to the main runway. No taxi queue is modeled on Runway 2 since aircraft are assumed to have immediate runway access. Tables 1 and 2 present the estimated emission rates for these respective source configurations. The emissions are categorized with respect to the individual sources and types of aircraft. Traffic densities are presented in terms of landing-takeoff cycles (LTO's). The assumed number of LTO's per hour (93) represents the mean plus one standard deviation of hourly traffic density experienced at Van Nuys during the heavy traffic time of day (9 AM until sunset) during August, 1976. This traffic density is considered a reasonable case for analysis in that it reflects conditions similar to those occurring at Van Nuys on a high density traffic day. For the 8-hour estimates only the first configuration using Runway 1 is analyzed.

Table 1 - Emission Rates Assumed in the Van Nuys Analysis, Assuming 93 LTO's Per Hour and Only One Runway in Use

Mode of Operation	Emission Rates	
	Single Engine Aircraft (65% of LTO's)	
Approach	5.1	gm/veh/sec
Landing	0.00081	gm/m/sec
Takeoff	0.0092	gm/m/sec
Climbout	8.5	gm/veh/sec
	Twin Engine Aircraft (28% of LTO's)	
Approach	16.	gm/veh/sec
Landing	0.00061	gm/m/sec
Takeoff	0.21	gm/m/sec
Climbout	31.	gm/veh/sec
	Single and Twin Composite Emission (93% of LTO's)*	
Taxiway	.0047	gm/m/sec
Taxiway Queue	.092	gm/m/sec
Run-up Area	.00069	gm/m^2/sec
Parking Area #1	.00017	gm/m^2/sec
Parking Area #2	.00017	gm/m^2/sec
Parking Area #3	.00017	gm/m^2/sec
Parking Area #4	.00020	gm/m^2/sec

*The remaining 7% of aircraft operations at Van Nuys are not considered in this analysis.

Table 2 - Emission Rates Assumed in the Van Nuys Analysis
(assuming 93 LTO's Per Hour and Both Runways in Use)

Mode of Operation	Emission Rates	
	Single Engine Aircraft (42% of LTO's); Runway 1	
Approach	5.1	gm/veh/sec
Landing	0.00053	gm/m/sec
Takeoff	0.0060	gm/veh/sec
Climbout	8.5	gm/veh/sec
	Single Engine Aircraft (23% of LTO's); Runway 2	
Approach	5.1	gm/veh/sec
Landing	0.00028	gm/m/sec
Takeoff	0.0032	gm/m/sec
Climbout	8.5	gm/veh/sec
	Twin Engine Aircraft (28% of LTO's); Runway 1	
Approach	16.	gm/veh/sec
Landing	0.00061	gm/m/sec
Takeoff	0.021	gm/m/sec
Climbout	31.	gm/veh/sec

Mode of Operation	Emission Rates	
	Single and Twin Engine Composite Emissions (70% of LTO's); Runway 1	
Taxiway	0.0036	gm/m/sec
Taxiway Queue	0.072	gm/m/sec
Run-up Area	0.00053	$gm/m^2/sec$
	Single Engine Emissions (23% of LTO's); Runway 2	
Taxiway	0.0011	gm/m/sec
Taxiway Queue	(none)	
Run-up Area	0.0016	$gm/m^2/sec$
	Parking Areas Single and Twin Engine Composite Emissions (93% of LTO's)*	
Parking Area #1	0.00017	$gm/m^2/sec$
Parking Area #2	0.00017	$gm/m^2/sec$
Parking Area #3	0.00017	$gm/m^2/sec$
Parking Area #4	0.00020	$gm/m^2/sec$

*The remaining 7% of aircraft operations at Van Nuys are not considered in this analysis.

RESULTS AND SUMMARY

The highest estimated 1-hour impact of general aviation aircraft on CO concentrations at Van Nuys Airport in this anlysis is 84 mg/m^3, about twice the 40 mg/m^3 NAAQS. The highest estimated 8-hour impact is 20 mg/m^3, twice the 10 mg/m^3 NAAQS. These high concentrations, however, are confined to CO hotspots near taxiway queues and run-up areas that are well within the airport boundaries. A few hundred meters downwind of the hotspots, maximum impacts are only small fractions of the standards.

Tables 3-5 present the highest estimated CO concentrations and the variation of concentration with downwind distance. In all cases traffic volume of 93 LTO's per hour is assumed.

Table 3 presents the maximum estimated 1-hour concentrations when all traffic uses the main runway (runway 1). In this case, stable atmospheric conditions (Pasquill Stability E) and a wind speed of 2 mps is used as meteorological input to the PAL model.

Table 3 - Maximum 1-Hour CO Concentrations*
versus Downwind Distance (assuming that all aircraft use Runway 1)

Nearest Upwind Source	Downwind Distance from point of Maximum Concentration											
	0.0	0.07	0.1	0.27	0.3	0.6	0.8	1.2	2	3	5	7
Taxiway 1	78	--	31	--	12	--	4	3	2	2	1	1
Run-up Area	84	19	--	7	--	--	3	2	2	2	1	1
Runway 1	31	18	--	8	--	--	3	2	2	2	1	1
Area 1	10	--	7	--	--	4	--	4	3	2	1	1
Area 2	7	--	4	--	--	2	--	2	1	1	1	1

Each dash (--) indicates that no concentration was estimated. *(mg/m^3)

Table 4 assumes the same meteorological condition as Table 3, but in this case 35 percent of the single engine aircraft are assumed to be diverted to runway and taxiway 2. Note that maximum concentrations in this case still exceed the NAAQS.

Table 4 - Maximum 1-Hour CO Concentrations*versus Downwind Distance (assuming that 35% of the single engine aircraft are diverted to Runway 2)

Nearest Upwind Source	Downwind Distance from point of Maximum Concentration (km)											
	0.0	0.07	0.1	0.27	0.3	0.6	0.8	1.2	2	3	5	7
Taxiway	55	--	21	--	8	--	3	2	2	1	1	1
Run-up Area	65	15	--	5	--	--	2	2	2	1	1	1
Runway 1	28	16	--	7	--	--	3	2	2	1	1	1
Area 1	10	--	7	--	--	4	--	4	3	2	1	1
Area 2	7	--	4	--	--	2	--	2	1	1	1	1

Each dash (--) indicates that no concentration was estimated. *(mg/m^3)

In Table 5, the estimated maximum 8-hour concentrations are tabulated. The maximum 8-hour concentrations are expected to occur when the wind persists from a single direction for about 4 consecutive hours of the heavy traffic period. In this case, all traffic is assumed to use the main runway.

Table 5 - Maximum 8-Hour CO Concentrations*versus Downwind Distance (assuming that all aircraft use Runway 1)

Nearest Upwind Source	Downwind Distance from Point of Maximum Concentration (km)											
	0.0	0.07	0.1	0.27	0.3	0.6	0.8	1.2	2	3	5	7
Taxiway 1	18	--	6	--	2	--	1	1	0	0	0	0
Run-up Area	20	5	--	1	--	--	1	0	0	0	0	0
Runway 1	7	4	--	2	--	--	1	0	0	0	0	0
Area 1	2	--	2	--	--	1	--	1	0	0	0	0
Area 2	2	--	1	--	--	0	--	0	0	0	0	0

Each dash (--) indicates that no concentration was estimated. *(mg/m^3)

Figure 3 portrays graphically the spatial distribution of concentrations summarized in Table 3. This figure is a plot of the maximum concentrations as a function of downwind distance.

In addition to noting the maximum CO concentrations, it is important to note how rapidly the concentrations decrease with downwind distance. Similar decreases with the distance are likely to occur with wind directions other than those assumed in this analysis. A wind direction parallel to the runways and taxiways is assumed in this analysis because, with the given source configuration, concentration estimates should be at least as high as they would be for any other wind direction.

In summary, this analysis present reasonable estimates of maximum CO concentrations due to general aviation aircraft emissions at Van Nuys Airport. Although this analysis does not yield conclusive evidence in terms of all general aviation aircraft at all airports, a potential scenario of their impact under some typical worst case emission and dispersion conditions has been developed.

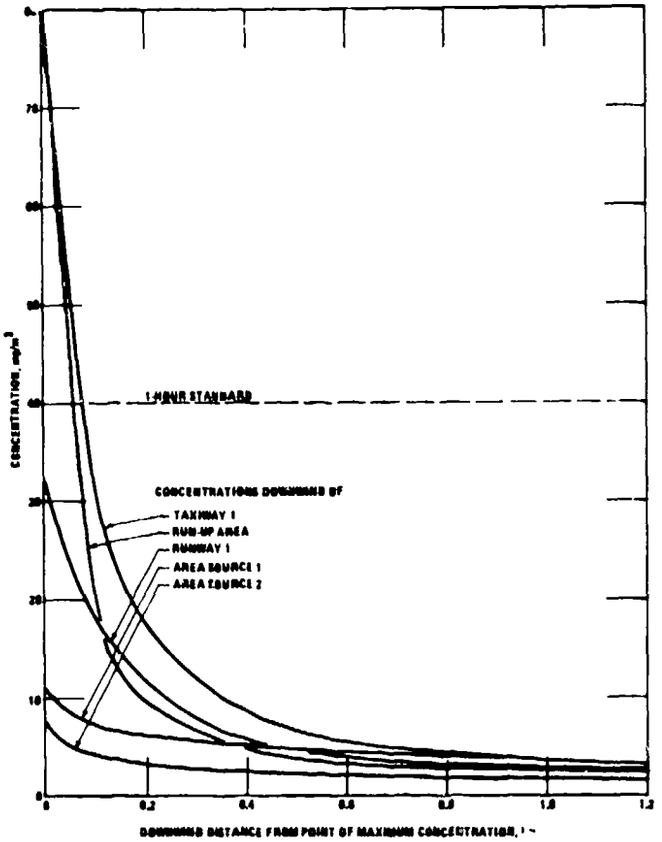


Fig. 3 - Maximum 1-hour CO concentrations as a function of downwind distance (assuming that all aircraft use Runway 1)

REFERENCES

1. W.B. Petersen, "User Guide for PAL, A Gaussian-Plume Algorithm for Point, Area, and Line Sources," Environmental Sciences Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-600/4-78-013, February, 1978.

2. "Compilation of Air Pollutant Factors," 2nd Edition, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, AP-42, February, 1976.

3. "Aircraft Emissions at Selected Airports 1972-1985," U.S. Environmental Protection Agency, Ann Arbor, Michigan, AC 77-01, January, 1977.

4. "Cessna Model 150--Owner's Manual," Cessna Aircraft Company, Wichita, Kansas, 1966.

DISCUSSION

SEGAL: Did you use the P-G curves in the modeling effort?

SCHEWE: Yes.

ROTE: Did you make allowance for the fact that the original P-G curves were for three-minute sampling times and you were computing hourly averages?

SCHEWE: We have applied them to hourly averaging times for about ten years, I think.

PASQUILL: I just wanted to ask if you attempted any adjustment of the P-G estimate to allow for the initial spread of the source for one reason or another as we discussed this morning?

SCHEWE: We did allow some turbulent wake.

PASQUILL: What sort of initial source sizes?

SCHEWE: Initial σ_z of about five to ten meters, possibly an initial σ_y of about three to seven meters, something like that.

GORDON: In exercising your model, when you extended your grid beyond the airport, did you encounter any circumstances where the CO emissions from the general aviation at the airport were contained in that area and accounted for any buildup in the background concentration or did you examine that facet?

SCHEWE: I think we probably neglected that. I am not sure I understand what you mean by the general aviation buildup beyond the boundaries.

GORDON: Assuming that your concentration profiles drop off that quickly with distance, I was wondering if you encountered any situations in local meteorology where the emissions, although they were dispersing away from the runway and queuing areas, were in fact being contained in the airport grid area so that they did cause, in conjunction with the freeways nearby, any cases where the air quality standard was violated due to containment within the grid system?

SCHEWE: No, I don't think we looked at that. We didn't look at any of the nearby expressways or anything, if I understand your question, but we did look out to about 15 to 20 kilometers with the model and really didn't find anything above about one milligram per cubic meter outside of that, if you want to consider that adding to the national air quality standard at those locations.

ENGINE EXHAUST PLUME GROWTH IN THE AIRPORT ENVIRONMENT

by
W. G. Tank and B. K. Hodder, Propulsion Research

Boeing Commercial Airplane Company
Seattle, Washington

The calculation of exhaust plume characteristics is a vital requirement to the prediction of ground-level concentration of effluents from tall industrial stacks. A similar requirement may be vital to the prediction of the effect of airplane exhaust emissions on air quality in the vicinity of airports.

Reference (1) presents a comprehensive study of airport air pollution analytical modeling techniques and compares predicted concentrations with a large sampling of measured concentrations from various aircraft types. Of particular value in this study was the measurement of pollution concentrations from single aircraft operations which were then compared with predictions from various modeling approaches. This approach allows the modeling to be representative of the particular source characteristics and therefore, more directly comparable with measured data. Even so, as discussed in Ref. (1), most of the analytical models still do not treat the details of the exhaust plume geometry and the assumptions made about effects of ambient winds may hamper the prediction of on-airport concentrations. For example, (1) utilized several analytical models to predict distances at which CO concentrations would be below a particular value from three different type aircraft. In general, all the models greatly overpredicted the distance obtained from measured data. These results typify the current problem of predicting farfield pollutant concentrations and give some insight into the possible cause for the problem as outlined in Fig. 1. The analytical modeling problem can be demonstrated by examining the Pasquill-Turner approach. This method requires the selection of an initial source size described by σ_{z_o} and σ_{y_o} (Fig. 2). Due to the lack of a proper data base, the σ_{z_o} and σ_{y_o} values commonly used do not represent particular plume geometries but simply the engine centerline ground clearance and spacing between engines.

To improve on-airport prediction capability, more understanding of the exhaust plume diffusion process seems to be necessary. Factors which can influence plume diffusion encompass engine geometry, ambient meteorology, and plume buoyancy. Reference (1) noted that accounting for plume rise effects (due to buoyant forces) was important to improving the agreement between measured and predicted pollutant concentrations. Ambient winds may play an important role from the standpoint that a large period of aircraft ramp and taxi operations forces the engine to exhaust into a range of wind directions anywhere from a crosswind to a tailwind. Data which can relate the effects of such ambient winds on exhaust plume diffusion is severely limited. Past and current work (2,3) in V/STOL aerodynamics can provide useful information as to trajectory and lateral growth of a jet issuing into a crosswind. Such information was utilized and expanded in (4,5) for the mixing of heated effluents flowing into a waterway. However, information about tailwind effects on exhaust plumes is essentially non-existent. Accordingly, it seemed appropriate to undertake a research program (Fig. 3) to obtain more experimental data on engine exhaust plume characteristics in the airport environment.

Our approach to studying plume diffusion was to find a way to make the plume visible so that its behavior under various conditions could be examined. The plume visualization method selected was infrared thermal imaging. Unlike other flow visualization techniques, infrared thermal imaging is not restricted to high speed flows or the introduction of some agent into the flow process to be examined. Infrared thermal imaging relies primarily on the temperature difference between the engine exhaust and the ambient medium. The infrared thermal imaging instrumentation used for the present program consisted of a tripod-mounted infrared camera and a display unit shown in Fig. 4. The infrared system uses a supercooled indium antimonide infrared detector which operates in the 2.4 to 5.0 micron band of the infrared spectrum. The system is capable of operating with a range of narrow bandpass filters for identifying specific gases. The thermal image of the optical field of view is obtained by a raster scanning technique and then forwarded to a CRT display (Fig. 5). A 16 mm motion picture camera synchronized to the raster display rate is being used to provide a permanent record of the thermal image and provide a means to record the dynamics and intermittency of the exhaust plume. State-of-the-art infrared thermal imaging systems can resolve temperature differences down to .2°C. However, system capability to detect a semi-transparent medium such as exhaust gases can be degraded by the transmittance of background infrared signatures involving both temperature and emissivity. As a result, exhaust plume geometries cannot be detected in all types of background conditions. To control the infrared background for the present exhaust plume measurements, the exhaust source (F-86F) was positioned in front of a large aircraft hangar (Fig. 6 and Fig. 7) which had a uniformly painted surface. Further, test periods during the day were chosen such that the front of the hangar was in the shade

thereby enhancing the exhaust plume - background temperature differential. Ambient winds are nominally parallel to the hangar orientation and the test area shown in the photograph of Fig. 8 is generally void of any large structures upwind which could grossly affect the ambient meteorology.

Preliminary test results (14-minute movie presented during oral presentation) have shown some important plume characteristics with a stationary source. At idle power and with a headwind plume diffusion followed the conventional jet spreading criteria (Fig. 9) up to an X/D value of 150. This data provides some of the first information about plume diffusion beyond X/D=40 where the bulk of existing experimental data stops. A more dramatic result was obtained at idle power and with a tailwind. The elevation of the exhaust plume trajectory was increased almost an order of magnitude near the source (Fig. 10). These results point to the pitfalls of assuming the vertical dimension σ_{z_o} of the initial source size to be the engine centerline ground clearance. Further, an increase in the initial source size will decrease the pollutant concentrations in the farfield.

Conclusions that can be drawn from this very preliminary work are summarized in Fig. 11. Since the present program represents only an encouraging beginning, our proposed future work (Figure 12) will hopefully delve more deeply and quantitatively into defining the engine exhaust diffusion process near the source in the airport environment.

REFERENCES

1. Smith, D. G., et al: Concorde Air Quality Monitoring and Analysis Program at Dulles International Airport. Report No. FAA-AQ-77-14, Vol. I and II, December 1977.

2. Anon: Analysis of a Jet in a Subsonic Crosswind. NASA SP-218, September 1969.

3. Fearn, R. L. and Weston, R. P. : Induced Velocity Field of a Jet in a Crossflow. NASA TP1087, May 1978.

4. Campbell, J. F. and Schetz, J. A. : Flow Properties of Submerged Heated Effluents in a Waterway. AIAA Journal, Vol. 11, No. 2, February 1973.

5. Campbell, J. F. and Schetz, J. A. : Penetration and Mixing of Heated Jets in a Waterway with Application to the Thermal Pollution Problem. AIAA Paper No. 71-524, Urban Technology Conference, May 1971.

PREDICTING THE IMPACT OF AIRCRAFT EMISSIONS

PROBLEM AREA

ENGINE EMISSION RATES EXTRAPOLATED TO FARFIELD
BY CURRENT ANALYTICAL MODELING TECHNIQUES
OVERPREDICT POLLUTANT CONCENTRATIONS.

POSSIBLE CAUSE OF PROBLEM

LACK OF PROPER MODELING OF EXHAUST PLUME
DIFFUSION NEAR THE SOURCE.

FIG. 1

TYPICAL ANALYTICAL MODELING PROBLEM

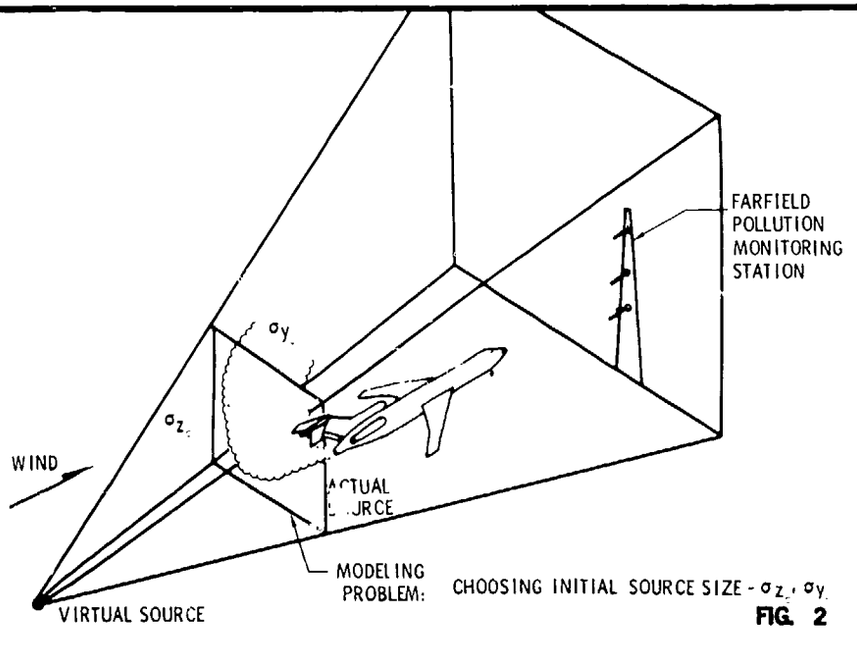


FIG. 2

TANK and HODDER

EXHAUST PLUME RESEARCH PROGRAM

OBJECTIVES

PROVIDE EXPERIMENTAL DATA THAT IDENTIFIES

EXHAUST PLUME DIFFUSION CHARACTERISTICS

IN THE AIRPORT ENVIRONMENT

- PLUME RISE
- CROSSWIND EFFECTS
- TAILWIND EFFECTS

APPROACH

FLOW VISUALIZATION USING INFRARED THERMAL IMAGING

FIG. 3

TANK and HODDER

TANK and HODDER

INFRARED CAMERA OPTICAL-MECHANICAL SCANNING MTD

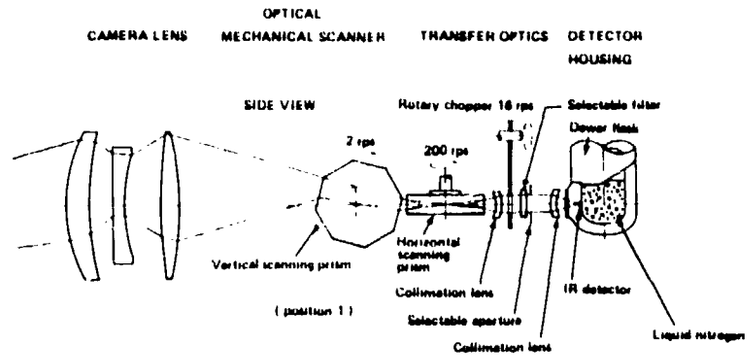
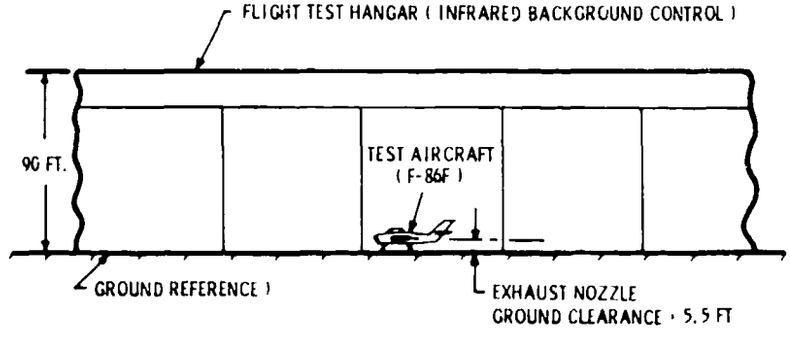


FIG. 5

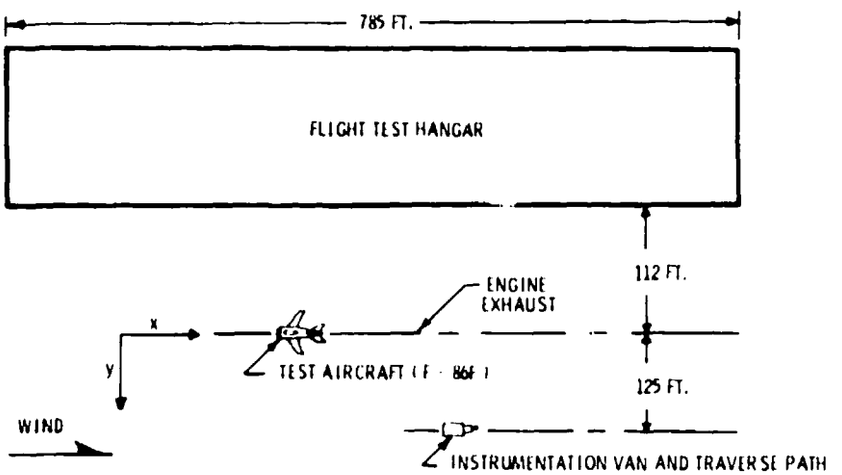
INFRARED EXHAUST TEST ARRANGEMENT



SIDE VIEW

FIG. 6

INFRARED EXHAUST TEST ARRANGEMENT



PLAN VIEW

FIG. 7

F-86F AIRCRAFT AND TEST AREA

TYPICAL PLUME CHARACTERISTICS WITH A HEADWIND

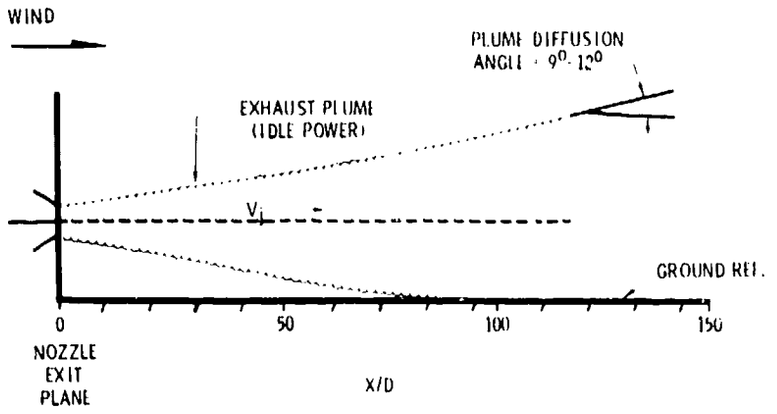


FIG. 9

TYPICAL PLUME CHARACTERISTICS WITH A TAILWIND

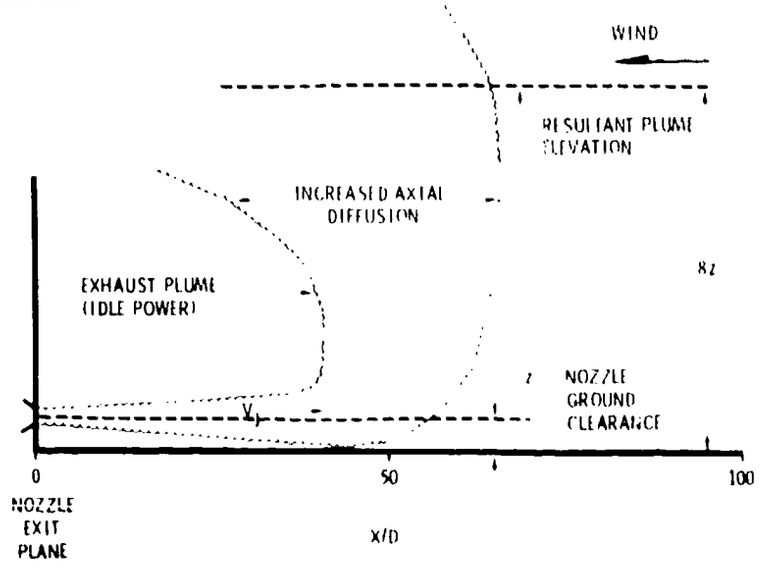


FIG. 10

CONCLUSIONS

1. TAILWIND CONDITIONS (IDLE POWER)

   (a) WINDS OF ONLY SEVERAL m / sec CAN INCREASE EXHAUST PLUME TRAJECTORY ELEVATIONS AT LEAST 8 TIMES.

   (b) SIGNIFICANTLY INCREASED AXIAL DIFFUSION OF THE PLUME.

2. HEAD WIND CONDITIONS (IDLE POWER)

   (a) PLUME THERMAL BUOYANCY EFFECTS WERE NOT IDENTIFIED UP TO $X/D \cdot 150$ WITH CLASS D STABILITY.

   (b) PLUME DIFFUSION APPEARS TO FOLLOW ESTABLISHED EMPIRICAL DATA.

3. FOR MODELING PURPOSES INITIAL SOURCE SIZE MAY BE MORE IMPORTANT THAN PLUME RISE EFFECTS.

FIG. 11

FUTURE EXHAUST PLUME RESEARCH

- OBTAIN PLUME CHARACTERISTICS ON COMMERCIAL TYPE AIRCRAFT AT BOTH IDLE AND TAKEOFF POWER
- INVESTIGATE SMALL-SCALE SIMULATION WITH A WIND TUNNEL
- ATTEMPT TO DEFINE METEOROLOGY CRITICAL TO SPECIFIC PLUME BEHAVIOR
- ANALYTICALLY MODEL MEASURED PLUME GROWTH CHARACTERISTICS

FIG. 12

DISCUSSION

ROTE: Your paper stimulates a lot of questions. One that concerned me at first was the trick of being able to photograph into the shadow. Are you not also exposing yourself to the turbulent wake created by the building, which would obviously affect what happens to the plume?

HODDER: I think that the best answer I can give to that is that we have looked at the building without the jet present, and there is no apparent activity, at least in terms of thermal wake from the building.

ROTE: No. I mean just the turbulence.

HODDER: The only thing I can say is that the wind direction does tend to parallel the building. We are off to the side of the building over 100 feet.

ROTE: How wide is the building?

HODDER: Probably a couple hundred feet wide; we haven't thoroughly investigated that. As I say, it is a progress report in the sense that we spent a lot of time just trying to get the technique to work, and that is something we have always got to be careful of.

NAUGLE: I enjoyed your paper and your slides on getting this thing to work. We have tried it in the Air Force unsuccessfully. We didn't do it in winds facing a building, and you have succeeded as we haven't.

I am trying to sort out the conclusions in the previous paper that there are CO hot spots with your findings, which indicate very significant plume characteristics that modelers typically don't account for.

I would really like to address a question to the previous author. Do you still have confidence in your conclusions regarding CO hot spots, or do you feel that maybe due to your simplified emission treatments, both in configuration and plume rise, this might be a modeling artifact?

SCHEWE: I don't see that as a problem. The models are only good within about a factor of two or three anyway, and we did allow for some initial dispersion, so I really don't see any problem.

He said that they noted dispersion up to about 35 to 50 feet, and, allowing some initial dispersion in our model up to about 30 to 35 feet, I don't feel we have any problems with that.

We did not allow for plume rise. I don't feel it was justified. There is no compelling reason for us to do that.

NAUGLE: What were the initial plume height and dimensions in the data that you presented?

SCHEWE: Offhand, I think it was about a meter and a half from the ground.

NAUGLE: And the dimensions?

SCHEWE: We allowed initial sigmas, in the model, of about 10 meters in the vertical, and about 3 to 7 or 8 meters in the horizontal. That is allowing for the turbulent wake of the vehicle moving and possibly a little bit for the plume rise, too.

NAUGLE: Do you think this would be adequate initial dispersion in light of what we just saw to account for these localized hot spots which did exceed standards in your analysis?

SCHEWE: Yes, I think so. I am not very familiar with engine temperatures. I'm not sure. This gentleman said that we were also dealing with prop engines and not jet aircraft, which may make some difference, too.

SEGAL: There are provisions in the models to accommodate an initial volume. The question is the basis for establishing the volume. I think this data is one of the first bases I have seen for coming up with dimensions. Once you define the dimensions, you can put them into your model.

HODDER: I might mention that there are other parts of the dimension picture we don't have yet, in particular, the lateral characteristics. We have looked up the tailpipe, but that is a difficult problem to calibrate because of the depth of the field.

I would like to look down at it from the top, but that would require going up on the top of the hangar and looking down. I'm trying to do that on a small scale.

D. SMITH: I was encouraged to see these preliminary results, because I think that when we talk about the Concorde project results a little bit more tomorrow, you will see that the range of conditions observed in that program suggests the range of effects you are seeing with the headwinds and tailwinds differing.

In fact, this kind of result will suggest to us maybe making a plain wind-angle orientation correction to the model so that in fact the initial dispersion volume could be direction specific, or orientation specific, I should say.

AIR QUALITY CHARACTERISTICS AT DULLES INTERNATIONAL AIRPORT FOR 1976, 1980, 1985, AND 1995

Eugene Shelar, Research Meteorologist

Atmospheric Sciences Laboratory
SRI International
Menlo Park, California 94025

ABSTRACT

Two analytical techniques have been used to estimate the air-quality impact associated with the development recommended in the Dulles International Airport Master Plan. First, a modified version of the Air Quality Assessment Model (AQAM) with worst-case meteorology was used to simulate the peak-month, peak-hour concentration of pollutants at several receptor sites. Then applications of the "Guidelines for Evaluating Indirect Sources" were used to provide estimates of pollutant concentrations resulting from vehicle congestion and queues at several locations at the airport.

The analysis with respect to CO indicated that the Federal one-hour standard would not be violated at the chosen receptors; however, under present emission patterns, the Federal eight-hour CO standard was likely to be exceeded at two receptors. Similar violations were not forecast for future years.

THIS PAPER SUMMARIZES the results of a research program that examined the air-quality impact associated with the development recommended by the Dulles International Airport (IAD) Master-Plan Update (1)*.

The air-quality study consisted of four major steps:

Step 1--Acquisition of air-quality and meteorological data from IAD.

Step 2--Definition of the current air quality in the study area.

Step 3--Determination of the air-quality impact associated with three planning alternatives for 1980, 1985, and 1995.

Step 4--Prediction of the air quality of IAD for the final, refined master plan for 1980, 1985, and 1995.

Available published reports that reviewed emissions, air quality, and meteorological conditions both at the airport and throughout the National Capital Interstate Air Quality Region provided the necessary data for the first step of the study. Steps 2 and 3, completed in January 1977, resulted in the recommendation that a remote parking lot be constructed as the best planning alternative, from an air-quality standpoint. This paper is concerned with the final step of the study, the prediction of future air quality.

A modified version of the Air Quality Assessment Model (AQAM) was used extensively during this study. The basic model was developed by Argonne National Laboratory for the Air Force (2). The basic model was modified to use emission factors from civil aviation sources. AQAM includes an extensive set of emission models for all air-pollutant generating activities, both stationary and mobile, on and around an airport, including airborne flight operations. The AQAM Short-Term Dispersion Model computes hourly averaged pollutant concentrations for a network of receptors.

METHODS USED TO ESTIMATE CARBON MONOXIDE IMPACTS AT DULLES

Before the impacts of Dulles airport could be projected, it was necessary to estimate current CO emissions in the area and to forecast the emissions expected in future years. A comprehensive emissions inventory of Dulles International Airport was developed from an operations inventory provided by Peat, Marwick, Mitchell & Co. A summary of the total emissions estimates for carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x), total suspended particulates (TSP), and oxides of sulfur (SO_x) from aircraft, vehicles, and point sources for 1976, 1980, 1985, and 1995 are shown in Table 1.

Aircraft and point source emission rates were obtained from AP-42 (3) or EPA/Ann Arbor (4). Vehicle emission rates through model year 1977 were determined from (3). It was assumed that model-years 1978 through 1980 would have the same emission rates as the 1977 models. At the time of the study, estimates of mean emission rates for future model year vehicles were not included in (3); however, (3) did set forth a table of emission factors for the six levels of emission standards that were given serious consideration. Table 2 shows the emission standards that were assumed for post-1980 light-duty vehicles.

AQAM was then updated to reflect the latest emission factors found in (3) by comparing AQAM exhaust emission rates with corresponding values in (3) to produce a correction factor.

After the emissions were estimated, the following steps were taken to assess the air-quality impact of Dulles:

Step 1--Worst-case background CO levels and the corresponding hour-by-hour sequence of wind speed, wind direction, and atmospheric

*Numbers in parentheses designate References at end of paper.

Table 1 - Summary of All Annual Emissions for Dulles International Airport for 1976, 1980, 1985, and 1995 (metric tons per year)

Year	Operation	Pollutant CO	HC	NO_x	TSP	SO_x
1976	Aircraft	1568.6	641.5	881.2	81.3	69.9
	Ground mobile	1281.8	123.9	90.6	30.0	22.7
	Point sources	5.6	129.7	76.3	18.6	101.7
1980	Aircraft	1909.5	706.9	1110.0	92.9	81.4
	Ground mobile	1080.7	111.6	92.5	28.0	19.5
	Point sources	6.8	156.6	92.5	22.6	123.3
1985	Aircraft	2429.9	902.6	1566.0	112.9	108.2
	Ground mobile	876.5	101.3	108.8	37.7	23.9
	Point sources	18.4	197.8	259.8	63.2	346.2
1995	Aircraft	4129.1	1184.9	3422.6	153.3	184.2
	Ground mobile	979.4	186.4	136.3	62.6	37.4
	Point sources	22.4	259.7	317.0	77.1	422.4

Table 2 - Assumed Federal Standards for Post-1980 Light-Duty Vehicles

Years	Pollutant (g/mi) CO	HC	NO_x
1981-1984	9.0	0.41	1.0
1985-1995	3.4	0.41	0.4

stability appropriate to Dulles Airport were determined.

Step 2--AQAM was used with the worst-case meteorological conditions and Dulles emissions data to simulate the 1976 contribution of emissions from Dulles for the peak-month, peak-hour concentration of CO at several receptor sites.

Step 3--EPA's Guidelines for Evaluating Indirect Sources (5) were used to calculate the excess CO concentrations resulting from vehicles idling at several highly congested points at the airport. This value was added to those from Step 2 and the background CO concentrations to provide an estimate of the expected CO concentrations at various receptors throughout Dulles.

Step 4--The input parameters for the forecast years, 1980, 1985, and 1995 were estimated.

Step 5--The projected CO at various receptors for the forecast years of Step 4 was calculated.

Several sources of meteorological data were used in the analysis. Of these, the "Concorde Monitoring Monthly Report" (6) was most useful. Its review showed the highest pollutant concentration occurring with light southerly winds. August was determined to be the peak-emissions month, and 5:00 p.m. to 6:00 p.m. the peak hour for air traffic; therefore, meteorological conditions appropriate to this period were selected. A series of dispersion calculations were made to determine which wind speed and direction would have the greatest effect on the simulated receptors. Overall, light winds (about 1 m/s) from 180° with a stable lapse rate (Pasquill-Gifford Type F) produced the worst-case pollutant concentrations. Historical data for August show that these meteorological conditions are rare, but possible. Accordingly, these conditions were chosen as worst case. For lack of other data, a mixing height of 300 m was arbitrarily chosen to represent worst-case conditions for the early evening.

The highest CO concentration reported during the Concorde monitoring study was 6.5 ppm (7.4 mg/m^3) at the South Ramp; this occurred on July 6 when the winds were from the south-southeast. Dispersion calculations using the Concorde South Ramp monitoring site as a receptor showed that a south-southeast wind would, in addition to the background level of CO, include a 1.2 mg/m^3 component from aircraft and other nearby sources. Subtracting this value from the South Ramp concentration produces a worst-case one-hour background CO level of 6.2 mg/m^3. The worst-case eight-hour CO concentration was 3.48 ppm (4.00 mg/m^3), which occurred from 12 noon through 8 p.m. on the same date.

The measured eight-hour maximum CO concentration agrees with one calculated using Larsen's conversion technique (7), which was used to estimate an eight-hour maximum from the maximum one-hour concentration. The value obtained using this method was also 4.0 mg/m^3.

The expected decrease of emissions in the Washington area resulting from stricter emission standards is described in MWCOG Technical Report No. 3 (8). The report shows the 1972 peak period emissions of CO to have been 877 tons and the projected 1992 peak period emissions for CO to be 349 tons. The decrease should cause a proportional lowering in the background CO concentrations. A linear interpolation between 1976 and 1995 emissions rates for the modeled years provided an emission weighting factor to reduce the 1976 background concentration to the required estimates of future year values. The factors used were 0.87, 0.70, and 0.35 for 1980, 1985, and 1995, respectively.

It was determined that vehicles could idle long enough at two locations to produce significant local effects. These locations were: (1) on the Dulles Access Highway near the East/West Service Road overpass, where many commuters make a U-turn, and (2) in front of the terminal building, near the

arrival and departure ramps. (Commuter vehicles were included only in the 1976 emissions inventory, reflecting an anticipated long-term solution of the commute traffic problem.)

The method used to determine the excess emission flux-density for these interrupted traffic flows is described by Dabberdt and Sandys (5), whose method showed that vehicles queuing at the Service Road intersection can raise the peak hour CO concentrations of a receptor placed near the intersection by up to 12.7 ppm (14.6 mg/m^3).

The methodology used to determine the excess CO concentrations due to queuing at the arrival and departure ramps was developed by Mancuso and Ludwig (9), whose method predicts CO concentrations in a street canyon. This method was necessary because of the aerodynamic effect the terminal structure has on pollutant concentrations. A south wind flowing over the terminal building can develop a helical air circulation so that receptors on the leeward side of the building are exposed to substantially higher concentrations than are those on the windward side. Table 3 shows the CO concentrations that should be added to nearby receptor because of the above effects. The decrease in excess concentrations from 1976 to 1995 is the result of the lengthening of the arrival and departure ramps and the imposition of stricter CO emission standards.

Table 3 - CO Concentrations at a Nearby Receptor Arising from Vehicles Queuing at the Arrival and Departure Ramps (mg/m^3)

Year	Concentrations from the Arrival Ramp	Concentrations from the Departure Ramp	Total Ramp Contributions
1976	7.56	4.21	11.78
1980	5.51	4.17	9.68
1985	2.36	2.54	4.90
1995	1.56	1.47	3.03

The idling emissions of buses were also included in the above calculations. However, their contribution to the overall CO problem is negligible. Even with long queuing times (875 seconds as opposed to a passenger car's 180 seconds), their CO contribution is small. The smallness of their contribution results from their very low CO emission rate (less than 0.02 g/s) and the relatively small number of buses compared to automobiles.

AIR QUALITY PROJECTIONS

Following the multistep procedure outlined earlier, worst-case meteorological and traffic data were used to define: the current (1976) CO concentrations at Dulles and CO levels expected for the years 1980, 1985, and 1995.

LOCAL WORST-CASE AIR QUALITY FOR 1976 - Fig. 1 shows the location of the receptor points and lines of constant worst-case hourly CO concentrations. The receptors were chosen to correspond to areas where people were likely to be exposed to this pollutant for moderate amounts of time. For example, Receptor 1 is in the remote aircraft parking apron; Receptor 2 is in the general aviation parking area. Receptor 3 is near the East/West Service Road overpass. Receptor 4 is in the parking lot near Building 67; Receptor 5 is in the cargo handling area; Receptor 6 is near the arrival and departure ramps, and Receptor 7 corresponds to the Concorde background pollutant monitoring site. The isolines show three areas of localized CO maxima. The first (4.24 mg/m^3), located near Building 67 (not visible in Fig. 1), is caused mainly by the large volume of vehicles that pass nearby, because of the Dulles Access Highway, parking lot, and arrival and departure ramps. The second area, located near the East/West Service Road overpass, has an hourly maximum concentration of 15.6 mg/m^3. This high concentration is caused primarily by the large number of commuter vehicles making the U-turn across the overpass. The third area of high concentration is near the arrival and departure ramps, where a value of 13.8 mg/m^3 can be expected under worst-case conditions. Note that the above concentrations do not include the contribution from CO emissions outside the immediate Dulles area.

LOCAL WORST-CASE AIR QUALITY FOR 1980, 1985, AND 1995 - Table 4 summarizes the expected CO concentration resulting from local sources at the seven receptors for each of the modeled years. The aircraft sources include concentrations relating to aircraft activity. The airport sources include all vehicles and point sources. Note that Receptor 3 shows a dramatic decrease in CO concentration from 1976 to 1980. This decrease results from the removal of commute traffic from future projections. Receptor 6 also shows a progressive decrease in CO concentration. This decrease results from the lengthening of the arrival and departure curbs and to the imposition of stricter CO emission standards.

Table 4 - Summary of Local Worst-Case Hourly CO Concentrations (Aircraft and Airport) for 1976, 1980, 1985, and 1995 at the Various Receptors (mg/m^3)

Receptor	Source	1976	1980	1985	1995
1	Aircraft	1.60	1.86	2.75	5.53
	Airport	0.21	0.16	0.08	0.05
	Total local	1.81	2.02	2.83	5.50
2	Aircraft	0.92	1.06	1.27	1.93
	Airport	0.40	0.29	0.14	0.10
	Total local	1.32	1.35	1.41	2.03
3	Aircraft	0.25	0.28	0.39	0.70
	Airport	15.38	0.71	0.56	0.70
	Total local	15.63	0.99	0.95	1.40
4	Aircraft	0.24	0.38	0.39	0.70
	Airport	4.00	4.28	3.12	2.40
	Total local	4.24	4.56	3.51	3.10
5	Aircraft	1.37	1.58	1.92	1.94
	Airport	0.35	0.26	0.13	0.84
	Total local	1.72	1.84	2.05	2.74
6	Aircraft	0.43	0.49	0.67	1.05
	Airport	13.80	7.94	6.40	4.81
	Total local	14.23	8.43	7.07	5.80
7	Aircraft	0.42	0.52	0.07	0.01
	Airport	0.52	0.38	0.18	0.12
	Total local	1.01	0.90	0.25	0.13

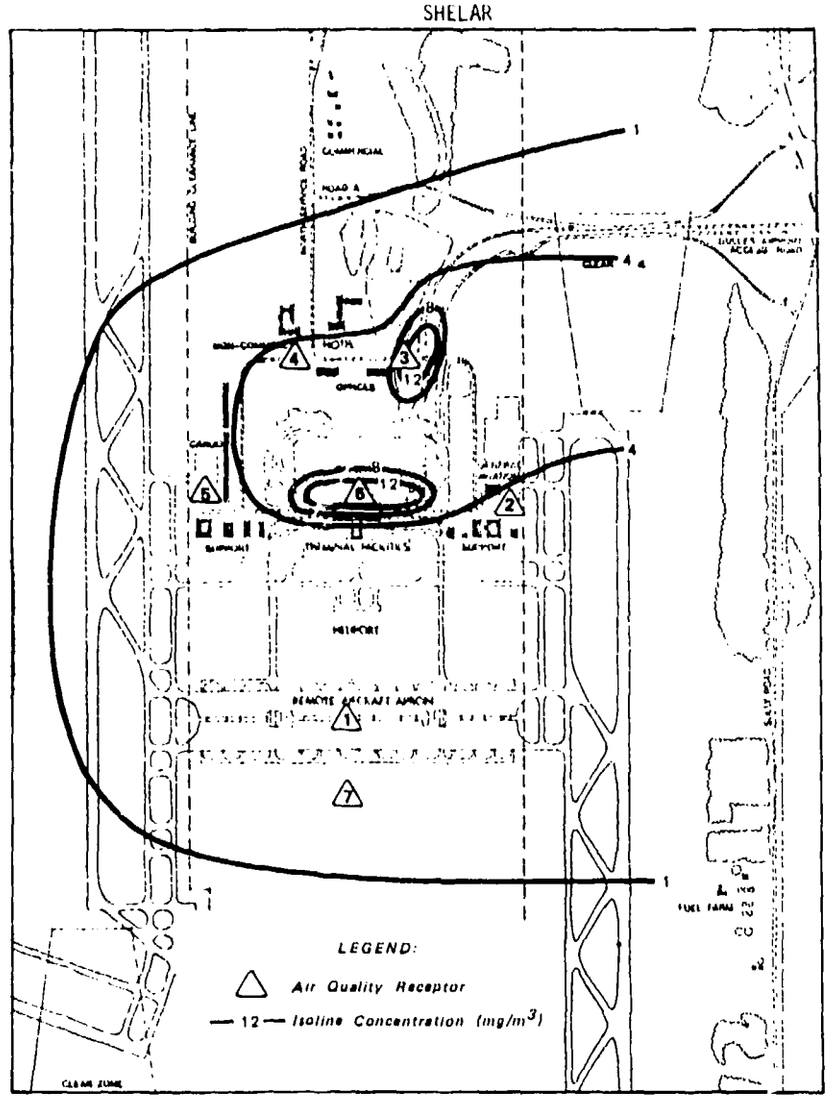


Fig. 1 - Isolines of local worst-case hourly CO concentrations for 1976

RESULTS AND CONCLUSIONS

Air-quality findings with respect to Federal standards are summarized below. The total hourly worst-case CO concentration is the sum of the background and local concentrations. This sum does not exceed the one-hour standard of 40 mg/m^3 for any of the projections.

The national primary eight-hour ambient air-quality standard for CO includes a maximum eight-hour concentration of 10 mg/m^3 (9 ppm) not to be exceeded more than once per year. Larsen's technique (7) was used to estimate worst-case eight-hour concentrations from the maximum predicted one-hour concentrations. Table 5 summarizes the results: the Federal eight-hour CO standard was only exceeded during 1976 at Receptors 3 and 6. Violations are not expected to continue in the forecast years because the lengthening of the arrival and departure ramps at the terminal, the elimination of commuter traffic from the East/West Service Road overpass, and the implementation of stricter vehicle emission standards will reduce the emissions that have been responsible for the standards violations. However, if one or more of these factors does not change as the predictions assume, then the Federal standards may be violated at these receptors in future years.

Table 5 - Summary of Worst-Case Eight-Hour CO Concentration for 1976, 1980, 1985 and 1995 (mg/m^3)

	Receptor Number						
Year	1	2	3	4	5	6	7
1976	4.4	4.0	10.2	5.5	4.3	10.1	4.0
1980	4.0	3.7	3.2	5.5	4.0	8.0	3.5
1985	3.8	3.3	3.2	4.4	3.6	5.6	2.7
1995	4.2	2.4	2.0	3.0	2.7	3.9	1.5

Based on the modeling analysis the following conclusions have been reached:

- The one-hour Federal Standard for CO, which did not appear to have been exceeded at Dulles in the base year 1976, is not likely to be exceeded in the forecast years 1980, 1985, and 1995.
- Violation of the eight-hour Federal primary standard was likely at the terminal building and East/West Service Road overpass during 1976.
- Adopting stricter vehicle emission standards, lengthening the arrival and departure ramps, and solving the East/West Service Road overpass commuter congestion will make violations of the eight-hour Federal standard unlikely in the forecast years.

REFERENCES

1. E. Shelar, "Air Quality Characteristics at Dulles International Airport for 1976, 1980, 1985, and 1995," SRI Report to Peat, Marwick, Mitchell & Co., SRI International, Menlo Park, California (1977).

2. D. M. Rote, et al., "A Generalized Air Quality Assessment Model (GAQAM) for Air Force Operations," AFWL-TR-74-304, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico (1974).

3. "Compilation of Air Pollutant Emission Factors," AP-42, through Supplement 8, EPA, Research Triangle Park, North Carolina (1978).

4. E. Munt, Environmental Protection Agency, Ann Arbor, Michigan, private communication (1977).

5. W. F. Dabberdt and R. C. Sandys, "Guidelines for Evaluating Indirect Sources," SRI Report to EPA under Contract No. 68-02-2073, Stanford Research Institute, Menlo Park, California (1976).

6. "Concorde Monitoring Monthly Report, Dulles International Airport, June 1976 - May 1977," Federal Aviation Administration, Department of Transportation (1977).

7. R. I. Larsen "A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards," EPA Publication AP-89 (1971).

8. "Air Pollution Emission Analysis of the Long Range Transportation Plan for the National Capital Region," Technical Report No. 3, Metropolitan Washington Council of Government (MWCG), Department of Health and Environmental Protection (1974).

9. R. L. Mancuso and F. L. Ludwig, "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program," SRI Report to CRC/EPA under Contract CAPA 3-68 (1-69), Stanford Research Institute, Menlo Park, California (1972).

DISCUSSION

TAYLOR: I wondered if, in your forecast of the aircraft traffic, you altered the fleet mix in future years?

SHELAR: Yes. If you mean with respect to the introduction of more Concorde runs, the introduction of new two-engine wide-body jets, and the reduction of 707's, the older aircraft, yes, we did.

TAYLOR: I did a similar calculation and found the concentrations decreasing in the future years with the new aircraft with the cleaner engines and the wide bodies. If you increase only the number of enplaned passengers and not the number of aircraft, which would in fact be the case (instead of using three 727s you take them out on one L-1011 or something like that) you get a decrease in CO.

SHELAR: My answer to that is that this operational inventory came from projections by the airlines. They projected a four-fold increase in the number of aircraft they were using. This included a mix of the wide-bodied, the new wide-body two-engine, three-engine and four-engine jets.

TAYLOR: You got the forecast from the airlines?

SHELAR: Yes.

TAYLOR: Mine is from the FAA.

GOODMAN: In this forecast, did you assume compliance with the retrofit requirements proposed by EPA in their March NPRM?

SHELAR: No, we didn't. This study was done in 1977. We assumed no aircraft emission controls. As you have seen, the major problem was not caused by aircraft, but by motor vehicles

D. SMITH: I might comment that the background monitor was selected for the worst case background. As I recall, there is a small parking lot there so that the background monitor is influenced by a local source to a small degree and, therefore, you probably had a conservative estimate of background.

SHELAR: Yes. We knew that, and we did subtract a local component away from it. We also compared the concentrations at the FAA site with concentrations measured in Herndon. We compared it with the downtown region and this value was consistent with that.

UPDATED MODEL ASSESSMENT OF POLLUTION AT MAJOR U.S. AIRPORTS

R. J. Yamartino and D. M. Rote

Argonne National Laboratory
Energy and Environmental Systems Division

ABSTRACT

The air quality impact of aircraft at and around Los Angeles International Airport (LAX) is simulated for hours of peak aircraft operation and "worst case" pollutant dispersion conditions. An updated version of the Argonne Airport Vicinity Air Pollution (AVAP) model is used in the simulation; model refinements reflect new theoretical formulations and data from field programs at LAX, O'Hare, and John F. Kennedy International Airports. Maximum carbon monoxide concentrations at LAX are found to be low relative to the NAAQS. Relatively high, widespread hydrocarbon levels indicate that aircraft emissions may aggravate oxidant problems near the airport. Concentrations of oxides of nitrogen are high enough relative to proposed standards to warrant further study. Similar modeling is underway for the O'Hare and JFK airports.

DURING THE PAST TEN YEARS, a number of agencies and groups concerned with the air quality impact of major airports have undertaken air pollution monitoring programs as well as theoretical studies based on the use of atmospheric dispersion algorithms. Lorang (1)* recently provided an extensive review and assessment of these efforts while Smith (2) has summarized the characteristics of, and approximations used in, the major air quality models used in the studies. Smith observes that the "Argonne Airport Vicinity Air Pollution Model (AVAP)(3) is the most sophisticated code yet developed for predicting the impact of all sources at commercial airports." Nevertheless, the AVAP code contains a number of assumptions and approximations that may require revision as new information becomes available regarding emissions inventory detail, aircraft operations, and plume dynamics.

This paper describes a simulation of the air quality impact of aircraft at and around Los Angeles (LAX) International Airport during hours of peak aircraft operation and under the most adverse dispersion conditions anticipated for those hours; no attempt is made to include the effect of nonaircraft sources. Similar simulation studies are underway for O'Hare (ORD) and John F. Kennedy (JFK) International Airports, but modeling results are not yet available. Data from a short field program at the three airports are also presented here. A detailed report on the studies for the three airports is in preparation. (4)

Updates and refinements used in the present AVAP assessment are based on recent literature as well as the results of the field program and include:

- Use of updated aircraft engine emission factors. (5)
- Direct input of the hourly number of aircraft departures by aircraft type. The new computerized Official Airline Guide (OAG) permits easy access to this previously difficult-to-obtain quantity and eliminates the need for estimating departures based on the time history of arriving aircraft.
- Inclusion of plume rise. Plume rise as observed in single-tower Dulles experiments (6) was input for the taxi/idle mode. The plume rise was taken as $\Delta H(ft) = 27.2 + 15.2/\sqrt{u(mph)}$, which represents an average for all aircraft types observed. No plume rise was considered for the other, high-speed, aircraft modes.
- Inclusion of enhanced vertical dispersion due to plume rise. The vertical dispersion coefficient was modified by the relation $\sigma_z^2(\text{modified}) = \sigma_z^2(\text{original}) + (\Delta H)^2/10$, as suggested by Pasquill. (7)
- Realistic modeling of the aircraft departure queue. Departure queue length and time-in-queue were input based on the field program.
- Use of revised airport-specific times-in-mode. Rising fuel costs as well as airport geometry and operational mode might cause time-in-mode factors to differ from the previously used factors found in the U.S. EPA's *Compilation of Air Pollutant Emission Factors*, AP-42 (8).

Other refinements used in or along with the AVAP computations include:

- Use of the Turner (9) time-dependent dispersion coefficients. For the light wind situations considered in this paper, these coefficients lead to substantially more rapid dispersion than the Turner (10) distance-dependent coefficients. Considerable evidence now exists to support the choice of the time-dependent dispersion approach under light wind conditions.
- Use of $1/r^p$ interpolation between grid points. Pollutant concentrations (doses) are known

*Numbers in parentheses designate References at end of paper

to fall off with a power of p 0.9 from line sources and p 1.8 from point sources. Use of linear interpolation tends to overestimate the area covered by high concentration contours resulting from localized pollution "hotspots." The average value p = (0.9 + 1.8)/2 = 1.35 is used in this study.

FIELD PROGRAM RESULTS

The field program at LAX, ORD, and JFK -- conducted by Dr. Douglas G. Smith and his associates from Environmental Research and Technology, Inc. (ERT) -- consisted of several days of observations (usually from the airports' control towers) of aircraft movements on the ground. These observations were supplemented by numerous conversations with tower chiefs and operations managers to determine those conditions leading to the greatest quantity of ground-level aircraft emissions. Season, day of the week, time of day, and meteorology were found to be the most significant factors in defining these "worst case" operational conditions.

Typical times-in-mode are given in Table 1 for departing aircraft and in Table 2 for arriving aircraft. Since most of the sampling periods coincided with the peak activity hours, the taxi/idle and queueing times listed may be overestimates of the diurnal average times. The times given in the *Compilation of Air Pollutant Emission Factors* (8) are included for comparison.

Table 3 presents the observed runway usage at the three airports. It should be noted, however, that these airports have more than one operational configuration of runway use and that the percentages in the table span multiple configurations. The actual runway and taxiway percentage utilizations by aircraft class for the configuration corresponding to "worst case" meteorological and operational conditions will be presented in the final report on this work. (4)

The diurnal variations in aircraft activity at the three airports are presented in Table 4. These data resulted from tabulation of operations for August 4, 1977, prepared by the Federal Aviation Administration using the computerized OAG data base. It should be noted that August is the busiest month at major U.S. airports and that Thursday (e.g., August 4) is the busiest day of the week. A finer breakdown for each of the 12 aircraft types considered will be given in the final report on these studies. (4)

Observations of gate usage as a function of aircraft type and taxi speeds as a function of aircraft mode (inbound or outbound) and taxiway segment also were made and will be tabulated in the final report. (4)

AIRPORT-INDEPENDENT MODEL INPUTS

AVAP requires rather detailed information regarding factors that determine the temporal and spatial distributions of pollutants as well as the

Table 1 - Typical Time-in-Mode for Departing Aircraft (mins)*

	Taxi/Idle			Queue			Total**	Takeoff			
Aircraft	JFK	ORD	LAX	JFK	ORD	LAX	AP-42	JFK	ORD	LAX	AP42+
Jumbo	11.35(6)	7.39(9)	6.89(33)	5.38(5)	8.27(6)	3.11(33)	19.00	.69(4)	.49(2)	.63(31)	.70
Long Range	8.46(2)	7.18(6)	7.61(17)	3.78(4)	6.94(6)	4.04(17)	19.00	.55(4)	.56(4)	.53(17)	.70
Med. Range	8.29(3)	7.00(16)	4.22(41)	2.92(2)	6.27(16)	4.75(43)	19.00	.63(2)	.39(6)	.53(44)	.70

* Number of aircraft in each sample indicated in parentheses.
**Includes taxi/idle and queue; from Reference 8.
+ From Reference 8.

Table 2 - Typical Time-in-Mode for Arriving Aircraft (mins)*

	Roll			Taxi/Idle			Total**
Aircraft	JFK	ORD	LAX	JFK	ORD	LAX	AP42
Jumbo	0.84(18)	1.00(1)	0.80(24)	6.78(18)	17.00(2)	5.42(21)	7.00
Long Range	0.61(18)	no data	0.75(23)	6.50(18)	no data	3.06(19)	7.00
Medium Range	0.60(22)	0.56(3)	0.68(51)	5.32(22)	6.72(4)	2.96(43)	7.00

* Number of aircraft in each sample indicated in parentheses.
**Includes roll and taxi/idle; from Reference 8.

Table 3 - Observed Runway Utilization (%)

Airport	Arrivals Runway	Arrivals % Use	Departures Runway	Departures % Use
O'Hare				
(9 arrivals,	22L	68	32R	47
36 departures	27R	11	32L	44
observed)	14L	11	27L	6
	14R	11	4L	3
John F. Kennedy				
(58 arrivals,	13L	86	13L	8
13 departures	13R	7	13R	85
observed)	22L	5	22L	8
	22R	2	22R	0
Los Angeles				
(80 arrivals,	24R	10	24R	2
90 departures	24L	10	24L	41
observed)	25R	46	25R	49
	25L	34	25L	8
LAX data from NOISE Network printout, 3/31/78				
	24	26	24	32
	25	74	25	68

Table 4 - Diurnal Variation in Airport Activity (August 4, 1977)

Hour	No. of Departures/Arrivals JFK	ORD	LAX
00-01	7/12	2/5	16/17
01-02	6/5	4/15	8/9
02-03	3/11	9/9	3/6
03-04	5/4	11/5	4/3
04-05	4/0	9/9	2/5
05-06	5/5	6/19	2/4
06-07	3/11	22/12	11/13
07-08	14/17	56/49	33/24
08-09	21/18	69/50	51/30
09-10	37/8	49/64	47/21
10-11	20/13	68/57	38/39
11-12	18/15	69/58	30/40
12-13	18/10	49/65	44/34
13-14	15/18	63/66	44/25
14-15	12/25	78/79	22/34
15-16	14/45	71/52	31/37
16-17	28/44	54/71	28/34
17-18	30/39	67/68	30/33
18-19	35/29	69/58	32/43
19-20	44/31	61/67	37/47
20-21	30/28	55/67	22/37
21-22	42/25	47/31	24/34
22-23	19/9	18/16	29/25
23-24	8/10	12/18	22/20

total mass of emissions. Table 5 lists the 12 aircraft types considered in the present simulations, along with the engine type and number of engines for each aircraft type. The aircraft also are assigned a class designation, which is a consideration in runway/taxiway usage, and a range, which affects aircraft time-in-mode via consideration of relative maneuverability on the ground. The emission rates of the 11 types of aircraft engines are given in Table 6.

MODEL ASSUMPTIONS AND RESULTS

The modeling results obtained for LAX are presented below. Similar evaluations for ORD and JFK are underway and will be described in the final report on this work. (4)

The diurnal cycle of aircraft arrivals and departures at LAX on August 4, 1977, is given in Fig. 1. As considerably more emissions of all pollutants accompany a departure, Hour 8 (0800-0900 PDT) is a likely "worst case" hour, with Hours 12 and 13 as possible alternative candidates. However, meteorological considerations rule out Hours 12 and 13; a moderate sea breeze usually develops by this time of day, resulting in rapid dispersion. Hour 8, on the other hand, is probably the last hour of the morning for which, in August, one would have the light wind, surface-based inversion conditions (11) that could lead to serious air pollution.

Hour 8 is thus selected as the "worst case" hour with assumed "worst case" meteorological conditions consisting of E stability, a 350-ft mixing depth (12), and a 2-knot wind with direction as yet unspecified.

Table 5 - Aircraft Classification Scheme

Type	Aircraft	Class	Range (miles)	Engine Manufacturer and Model Number	No. of Engines	Auxiliary Power Unit
1	747	Jumbo/wide body	5,000-8,000	Pratt & Whitney, JT9D-7	4	yes
2	L1011	Jumbo/wide body	5,000-8,000	Rolls Royce, RB-211-22B	3	yes
3	DC10	Jumbo/wide body	5,000-8,000	General Electric, CF6-6D	3	yes
4	D11	Jumbo/wide body	5,000-8,000	General Electric, CF6-50C	3	yes
5	707, DC8	Long-range	3,000-5,000	Pratt & Whitney, JT3D-7	4	no
6	727	Medium-range	1,000-3,000	Pratt & Whitney, JT8D-17	3	yes
7	737, DC9, B11	Medium-range	1,000-3,000	Pratt & Whitney, JT8D-17	2	yes
8	DC3, PAN, CN4	Turboprop	1,000-3,000	AVCO Lycoming, T1D540 12B2	2	no
9	LOE, DBH	Turboprop	1,000-3,000	Garrett AiResearch, TPE/31-2	2	no
10	FKF, CV5, FK7	Turboprop	1,000-3,000	Rolls Royce, RDa7	2	no
11	HPJ, DHT, SWM, ND2, DHH, BE9	Small turboprop	<1,000	Pratt & Whitney, PT6A-27	2	no
12	DAF	Small turboprop	<1,000	General Electric, 700-2D	2	no

Table 6 - Emission Rates of Aircraft Engines*

Engine Manufacturer and Model	Taxi/Idle	Landing	Take-off	Approach	Climbout
			Carbon Monoxide		
Pratt & Whitney, JT9D-7	142.2	93.4	3.2	44.6	6.6
Pratt & Whitney, JT3D-7	140.8	96.3	9.0	60.1	15.6
Rolls Royce, RB-211-22B	137.6	98.9	5.6	93.8	14.9
General Electric, CF6-50C	88.0	56.6	0.4	22.7	4.7
General Electric, CF6-6D	65.1	44.7	8.3	23.2	6.8
Pratt & Whitney, JT8D-17	39.1	28.4	7.0	20.2	7.9
Rolls Royce, RDa7		27.1	4.8	21.5	4.3
Garrett AiResearch, TPE731-2	11	8.6	1.9	9.5	1.8
Pratt & Whitney, PT6A-27		5.3	0.4	4.9	0.5
General Electric, 700-2D		65.7	57.4	57.0	58.1
AVCO Lycoming, TIO540 J2B2		129.4	374.5	125.4	300.8
			Hydrocarbons		
Pratt & Whitney, JT9D-7	55.1	34.0	0.8	4.6	1.3
Pratt & Whitney, JT3D-7	124.6	77.0	5.0	6.5	3.3
Rolls Royce, RB-211-22B	100.1	72.2	29.1	32.2	8.3
General Electric, CF6-50C	36.2	21.8	0.2	0.1	0.2
General Electric, CF6-6D	21.8	16.2	8.3	7.0	6.8
Pratt & Whitney, JT8D-17	10.1	6.4	0.5	1.4	0.4
Rolls Royce, RDa7	25.5	17.4	8.8	0.0	2.1
Garrett AiResearch, TPE731-2	4.1	2.7	0.1	1.5	0.1
Pratt & Whitney, PT6A-27	5.8	3.5	0.0	0.5	0.0
General Electric, 700-2D	8.3	5.2	0.3	1.3	0.2
AVCO Lycoming, TIO540 J2B2	1.7	2.0	3.2	1.3	3.4
			Oxides of Nitrogen		
Pratt & Whitney, JT9D-7	5.73	123.14	474.60	35.25	282.30
Pratt & Whitney, JT3D-7	2.23	34.29	126.40	16.35	78.60
Rolls Royce, RB-211-22B	5.31	129.31	504.10	32.26	301.90
General Electric, CF6-50C	3.02	171.29	670.95	52.80	462.20
General Electric, CF6-6D	4.88	121.77	467.50	41.54	309.20
Pratt & Whitney, JT8D-17	3.91	53.94	202.06	19.39	123.40
Rolls Royce, RDa7	0.29	2.31	8.51	0.57	5.55
Garrett AiResearch, TPE731-2	0.54	8.05	29.80	3.59	7.18
Pratt & Whitney, PT6A-27	0.28	1.25	3.32	1.80	2.80
General Electric, 700-2D	0.82	4.26	14.60	1.65	9.98
AVCO Lycoming, TIO540 J2B2	0.01	0.05	0.09	0.13	0.05

*All emission rates except those for landing are from Reference 5. The landing emission rates are computed by assuming that the landing operation consists of 60% idle, 24% takeoff thrust (i.e., thrust reversers), and 16% approach thrust (to account for the spool down/up/down cycle).

Figure 2 depicts the major aircraft line sources at LAX, including runways, taxiways, queueing segments, and terminal zone connectors. A breakdown of the Hour 8 aircraft emissions by line source type is given in Table 7. Comparison of the ground level figures with the automotive emission rates in Reference 8 suggests that the airport aircraft equivalent in number of cars is ≈500 at idle for carbon monoxide (CO), ≈2600 at idle for total hydrocarbons (THC), and ≈800 at 45 mph for oxides of nitrogen (NO_x).

AVAP computations were performed using a 0.25 mile receptor grid (note that Fig. 2 has a superimposed 0.5 mile grid) for wind directions of $\theta = 360°$ (Fig. 3), $\theta = 100°$ (Fig. 4), and $\theta = 270°$ (Fig. 5). The west ($\theta = 270°$) wind computations were then redone (Fig. 6) for the eastern portion of the southern runway complex to show the result of using increased grid resolution (0.05 mile). It should be noted, however, that the light winds in the morning are almost always from the east and rarely from the west or north.

The major inferences to be drawn from Figs. 3-6 and from accompanying isopleths (not shown) for THC and NO_x are summarized in Table 8. Maximum hourly average carbon monoxide concentrations are found to be low compared to the National Ambient Air Quality Standards limit of 35 ppm. Hydrocarbon levels of a few ppm, while not a direct health hazard, are high compared to the 6-9 a.m. guideline value of 0.24 ppm. The area covered by the 0.25 ppm THC contour is estimated to be several times the airport area, so that aircraft-contributed hydrocarbon emissions may indeed aggravate oxidant

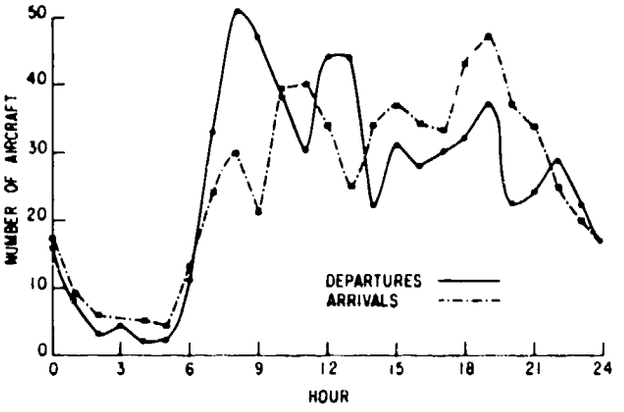


Fig. 1 - Hourly number of arrivals and departures at LAX versus hour of the day

Table 7 - Summary of Aircraft Emissions for Hour 8 (0800-0900 PDT) at LAX

Location	Emissions (10^3 lbs) CO	THC	NO_x
Runways	0.04	0.02	0.44
Taxiways	1.47	0.80	0.08
Queue	1.28	0.74	0.07
Terminal	0.38	0.18	0.04
Total on ground	3.17	1.74	0.63
Approach and climbout	0.14	0.02	0.81
Total	3.31	1.76	1.44

problems in the airport vicinity. Finally, NO_x values are comparable to the potential nitrogen dioxide (NO_2) hourly standard of 0.2-0.5 ppm, which suggests a more detailed look at the NO_2 situation either observationally or via models that include ozone limitation of the reaction $NO + O_3 \rightarrow NO_2 + O_2$ and NO_2 photolysis.

ACKNOWLEDGMENT

This work was supported by the Federal Aviation Administration Office of Environmental Quality.

REFERENCES

1. P. Lorang, "Review of Past Studies Addressing the Potential Impact of CO, HC, and NO Emissions from Commercial Aircraft on Air Quality." U.S. Environmental Protection Agency (U.S. EPA) report AC-78-03, March 1978.

2. D.G. Smith, "Airport Air Quality Modeling - Recent Developments." Proc. Spring Technical Meeting of Northeast Atlantic International Section of Air Pollution Control Assn., Wakefield, Mass., April 1978, pp. 41-69.

3. I.T. Wang, L.A. Conley, and D.M. Rote, "Airport Vicinity Air Pollution Model User Guide." Federal Aviation Administration (FAA) Report FAA-RD-75-230, Dec. 1975.

4. R.J. Yamartino, D.G. Smith, and E.A. Taylor, "An Updated Model Assessment of Aircraft Generated Air Pollution at LAX, JFK, and ORD." FAA report, to be published.

5. R.G. Pace, "Technical Support Report - Aircraft Emissions Factors." U.S. EPA Report, March 1977.

6. D.G. Smith, et al., "Concorde Air Quality Monitoring and Analysis Program at Dulles International Airport." FAA-AEQ-77-14, Dec. 1977.

7. F. Pasquill, "Atmospheric Dispersion Parameters in Gaussian Plume Modeling: Part II. Possible Requirements for Change in the Turner Workbook Values." EPA-600/4-76-030b, June 1976.

8. "Compilation of Air Pollution Emission Factors." U.S. EPA Report AP-42, 2nd Ed., March 1975.

9. D.B. Turner, U.S. EPA, private communication, 1970.

10. D.B. Turner, "Workbook of Atmospheric Dispersion Estimates." U.S. Dept. of HEW/Public Health Service Report 999-AP-26,1968.

11. R. Keith, South Coast Air Quality Management District (formerly Los Angeles Air Pollution Control District), private communication, 1978.

12. N.L. Hallenger, "Meteorological Factors in Air Pollutant Emission Factors." U.S. EPA Report AP-42, 2nd Ed., March 1975.

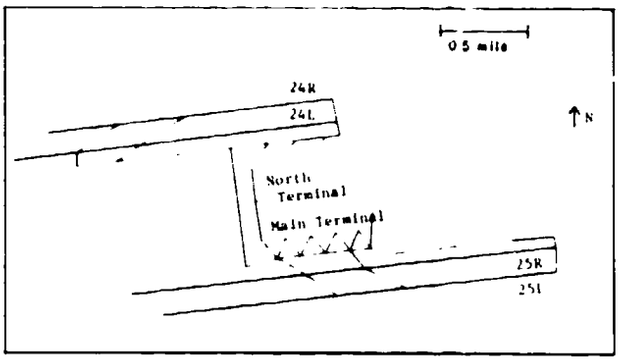


Fig. 2 - Map of aircraft line sources at LAX

Table 8 - "Worst Case" Concentrations at LAX for Hour 8 - Worse Case Meteorological Conditions Consist of E Stability, a 2 Knot Wind, a 350' Mixing Depth, and a Wind Direction as Given Below

Location	Wind Direction	Hourly Average Concentration (ppm) CO	THC	NO_x
Entire terminal	100°	1.5	1.5	0.15
North terminal area	360°	2.0	2.0	0.2
Downwind Distance from leading line source				
0.25 mile	360°	2.0	2.0	0.25
0.50 mile	360°	≈1.3	≈1.3	0.15
0.25 mile	270°	3.5	4.0	0.45
0.50 mile	270°	2.5	2.5	0.30
1.50 mile	270°	1.5	1.5	0.20

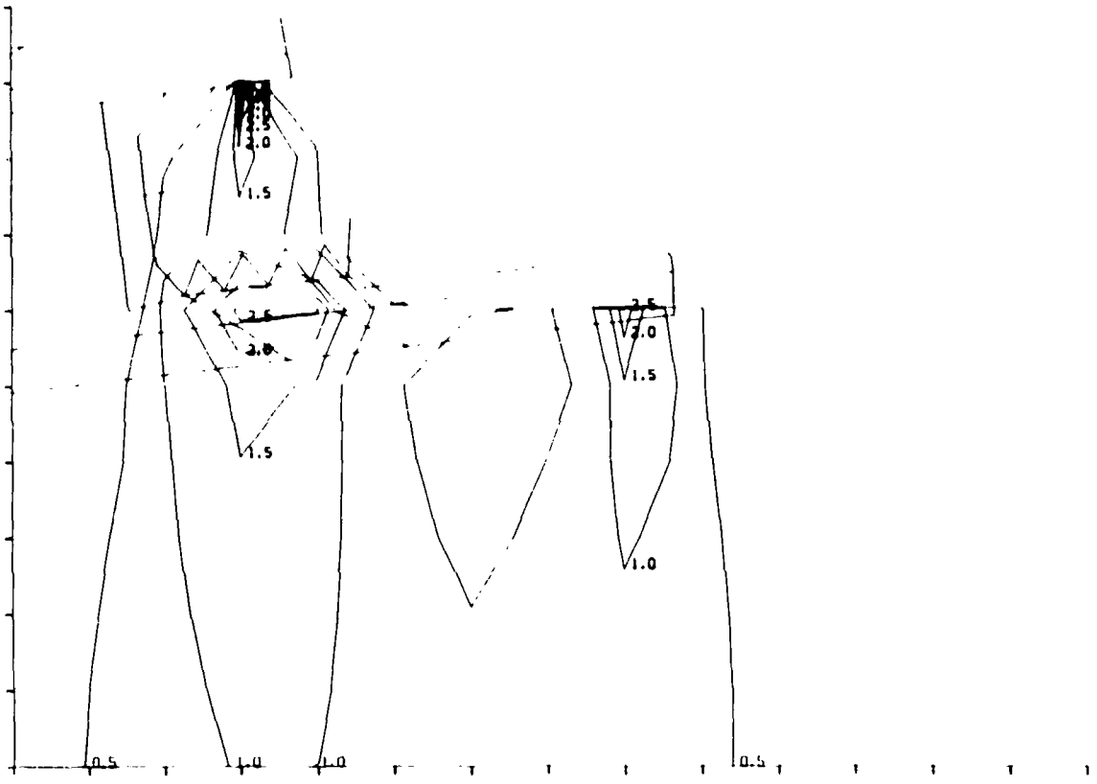


Fig. 3 - CO concentration isopleths (ppm) from aircraft operations at LAX for hour 8 assuming E stability, a 350' mixing depth, and a 2 knot wind from the north (θ = 360°) - grid size = 0.25 miles

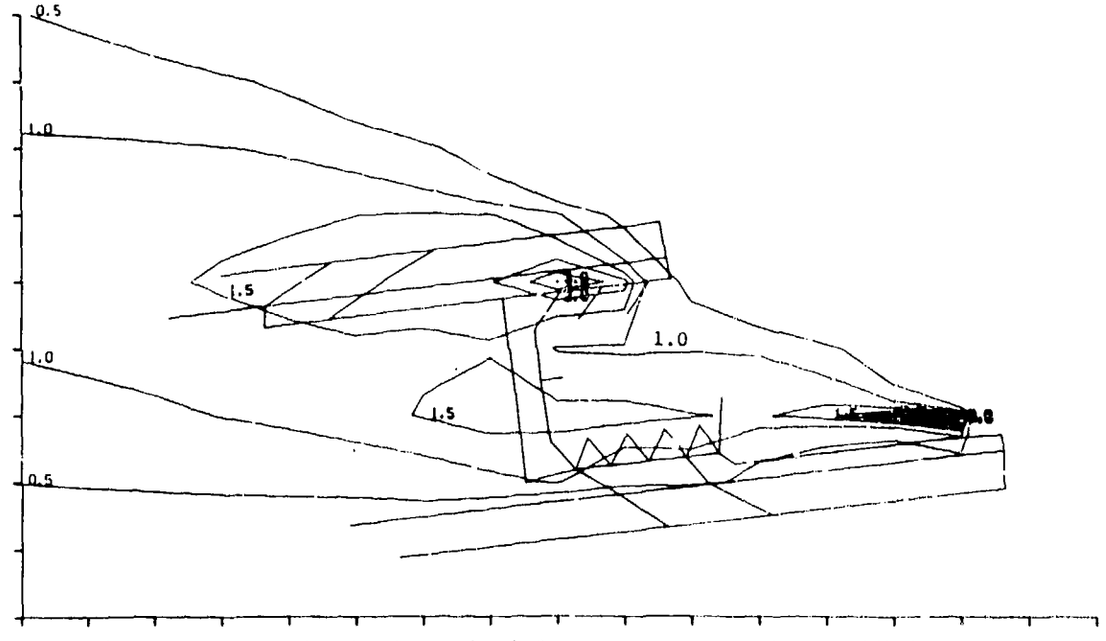


Fig. 4 - CO concentration isopleths (ppm) from aircraft operations at LAX for hour 8, assuming E stability, a 350' mixing depth and a 2 knot wind from the east (θ = 100°) - grid size = 0.25 miles

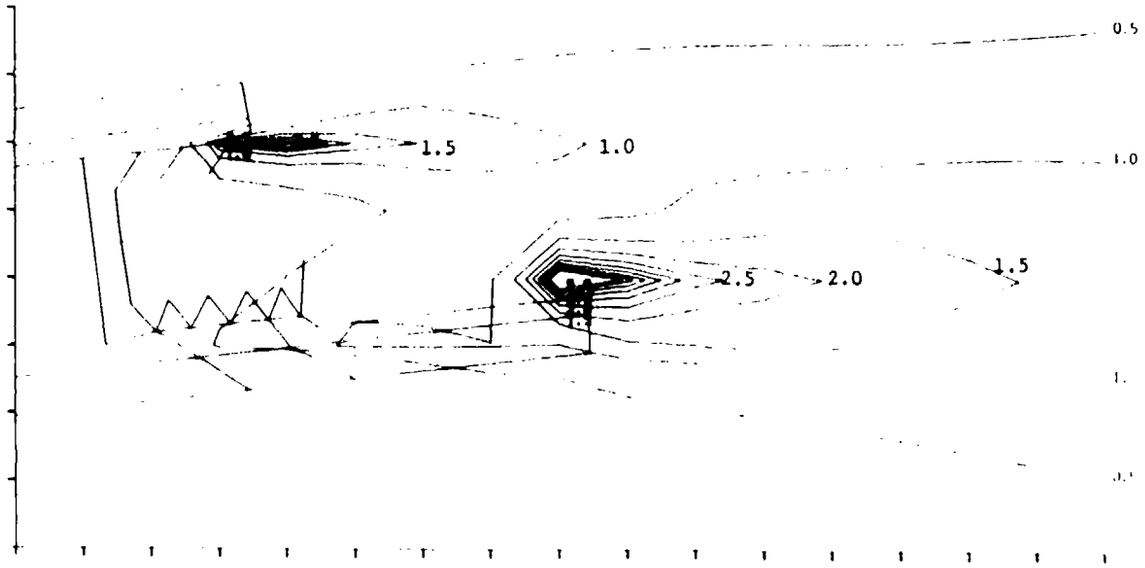


Fig. 5 - CO concentration isopleths (ppm) from aircraft operations at LAX for hour 8 assuming E stability, a 350' mixing depth, and a 2 knot wind from the west (θ = 270°) - grid size = 0.25 miles

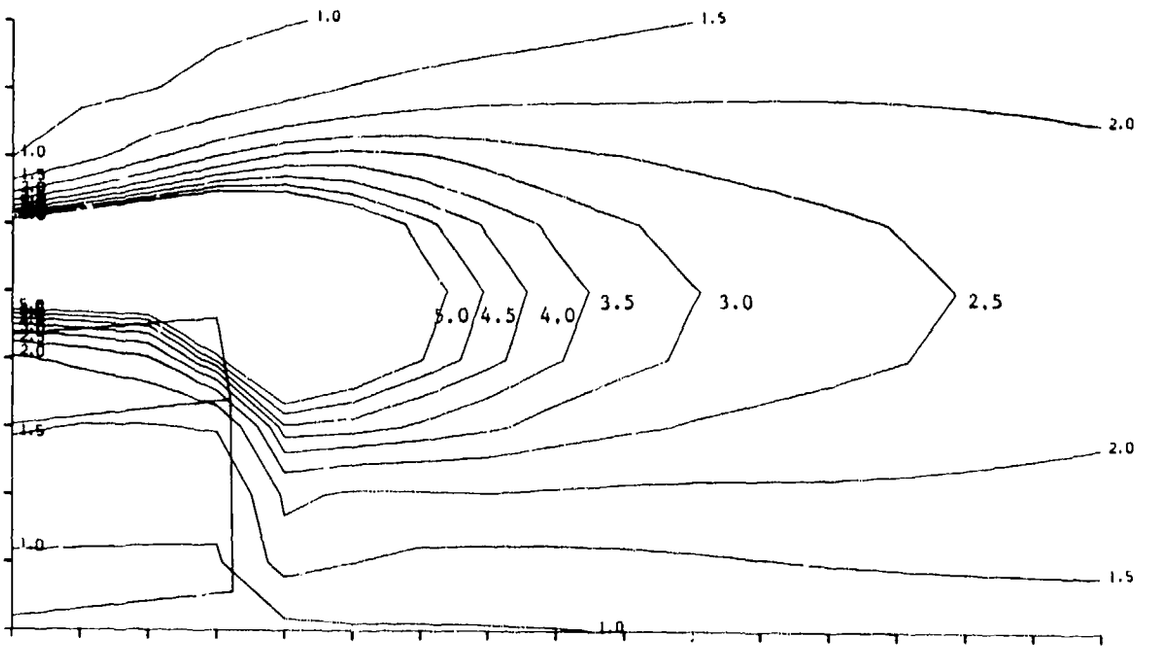


Fig. 6 - CO concentration isopleths (ppm) from aircraft operations at LAX for hour 8 assuming E stability, a 350' mixing depth, and a 2 knot wind from the west (θ = 270°) - grid size = 0.05 miles

DISCUSSION

PASQUILL: I don't think this can be resolved here today. I am mystified at this reference to the use of time-dependent sigmas. You remind me by referring to it that I talked to Bruce Turner about this two or three years ago. I think there is something quite mystifying about the fact that one claims to get different sigmas as one considers the distance of travel or the time of travel because, after all, any of these estimates are basically for a receptor at a fixed distance from the source.

You can perfectly reasonably then transform that into a time of travel by putting in the wind field, but the two must be consistent. I find it quite mystifying if you take either a distance of travel or a time of travel, you get a very different sigma.

YAMARTINO: You should be able to just substitute, T equals X over U.

PASQUILL: You want to be careful about the U because the wind varies with height. The two should be mutually consistent.

YAMARTINO: As the wind speed goes to zero, you run into problems with the downwind distance. The whole concept of σ_θ becomes rather nebulous because the σ_θ that would belong in a Gaussian type representation is no longer the same σ_θ you would get if you mensured it in the field. In fact, the σ_θ would go to infinity in order to get an isotropic distribution.

There are all kinds of problems that seem to come in as you let the wind speed go to zero. I don't think enough has been done at the low wind speeds or enough in terms of experimental efforts. Yet regulatory agencies always insist that the simulations be done at these low-wind-speed worst-case conditions.

There seems to be a sort of a problem there.

PASQUILL: I think there is a problem, yes.

ROTE: Another point is worth mentioning, Frank, and that is that as you know, for example, with the McElroy-Pooler data, these coefficients may not be completely consistent. The reason is that they represent independent fits to the data.

For example, if you look at downwind distance dependence, you ignore wind speed except for the classification by Pasquill-Gifford stability category, and you have a whole lot of data, and then you must associate a single point with all that data, which requires some kind of a least-squares fitting procedure.

Now, therefore, when you end up with a coefficient which is not necessarily kinematically consistent with the completely different fitting prescription, that rather measures the travel time downwind as opposed to downwind distance.

PASQUILL: I accepted that you make different relations between sigma and time and distance because of the wind-speed effect.

What I am saying is that since basically you estimate of sigma is either a measurement of the position or it is a theoretical solution which would be for a given position, then you can't alter that by looking at it either in the time or distance frame, if you relate the time and distance frames consistently.

ROTE: I agree.

ROTE: I should point out that the values Bob showed for the time-dependent coefficients were very similar to those obtained by McElroy-Pooler in the two cases. The McElroy-Pooler measurements were performed in an urban environment.

D. SMITH: A quick clarification: I don't know if you mentioned this was aircraft only.

YAMARTINO: All of these simulations involved aircraft only. There were no axis vehicles or service vehicles of any kind.

ON THE DISCRETE ASPECT OF POLLUTION JETS FROM AIRCRAFT TAKEOFFS

Ernest Bauer

Institute for Defense Analyses
Arlington, Virginia 22202

Consider the problem of a runway with N commercial operations per hour. The (NO_x or particulate) pollution is measured at a distance x_o (1 mile, or 1.5 km) downwind from the starting end of the runway, and one asks under what conditions the pollution may be described as a continuous source rather than as a series of separate puffs.

The answer depends not only on N, x_o, and the effective wind speed u, but also on the behavior of downwind dispersion $\sigma_x(t)$. Here one may use the result of Draxler (1), who provides the first explicit data on $\sigma_x(t)$ in the form

$$\sigma_x(t) = 7.3\ t^{1.3} \quad (\sigma_x \text{ in meters, t in minutes, for times 10 minutes to several hours}) \qquad (1)$$

Alternately one could use existing data on cross-wind dispersion $\sigma_y(t)$ — see, e.g., Reference (2), with $t = x/u$, or Reference (3), with the approximate relation

$$\sigma_x(t) = A\ \sigma_y(t), \qquad A \simeq 1 \qquad (2)$$

which has been used extensively, and gives results that are rather similar to Eq. (1).

Commercial jet operations will tend to be spaced uniformly, so that the average interval between takeoffs will be (60/N) minutes, or 2.4 minutes for N = 25/hour. As the engines are run up to takeoff thrust at the end of the runway, the NO_x and particulate emissions increase drastically; the emission rate in kg/sec remains constant, but because of the acceleration of the aircraft the effective emission in kg/meter starts off at a very high value, then falls off inversely with speed as the airplane accelerates, giving rise to a puff with a sharp starting edge and a gradual tailing off. Let us assume an effective puff duration of 15 seconds (0.3 - 0.5 of the takeoff run) and a wind speed u = 3 m/sec (6 knots).

It takes x_o/u for the exhaust puff from a single takeoff to travel a distance x_o downwind; for the present parameters, x_o = 1500 m, u = 3 m/sec, this is 8.3 minutes, and thus from Eq. (1) at the monitoring station the length of the puff will be 100 m for a very short initial puff, or 200 m for a 50 m long initial puff (initial length = (duration) x (wind speed)). The spacing between successive puffs is d = u/N or 430 m for the present conditions, which is very much greater than the mean width of the puffs. Accordingly, the puffs ought to be treated as discrete under these conditions, if one asks for the instantaneous rather than the integrated pollutant dose.

Evidently, sufficiently far down from the end of the runway the puffs will spread out so that their discreteness is no longer significant; thus from Eq. (1) σ_x = d after an interval of 23 minutes from the takeoff, or at a distance of 3.4 - 4.1 km (2.0 - 2.6 miles) from the end of the runway, so that at distances significantly greater than this the assumption of a continuous source is satisfactory.

The present argument clearly does not depend on the precise form of Eq. (1). Further, if the effective wind speed is greater than 6 knots — e.g., if the effective speed of the exhaust is taken into account — the puff will be younger and hence more discrete when it passes the 1 mile/1.5 km point, and thus the present estimate is conservative.

I am indebted to Mr. A. J. Broderick for asking the question. This work was supported by the Federal Aviation Administration under Contract No. DOT-FA-77WA3965.

REFERENCES

1. R. R. Draxler, "Some Observations of the Along-Wind Dispersion Parameter," ms, 1978, to be presented at the Fourth Symposium on Turbulence, Diffusion and Air Pollution, sponsored by AMS, Jan. 1979, Reno.

2. D. B. Turner, "Workbook of Atmospheric Dispersion Estimates," Environmental Protection Agency Report AP-26, revised 1970.

3. E. Bauer, "Dispersion of Tracers in the Atmosphere," Institute for Defense Analyses, Paper P-925, Feb. 1973 - see also J. Geophys. Res. 79, 789, 1974.

CASE STUDIES AND DATA BASE

Co-Chairmen: R. W. Boubel
Air Pollution Control Association

P. S. Daley
United States Air Force

REDUCING AIR POLLUTANT EMISSIONS AT AIRPORTS BY CONTROLLING AIRCRAFT GROUND OPERATIONS

Mr. C. Gary Gelinas, Pacific Environmental Services, Inc.*
Dr. Henry S.L. Fan, Peat, Marwick, Mitchell & Co.

Pacific Environmental Services, Inc.
Santa Monica, California, U.S.A.

Peat, Marwick, Mitchell & Co.
San Francisco, California, U.S.A.

ABSTRACT

Potential reductions in air pollutant emissions were determined for four strategies to control aircraft ground operations at two case study airports, Los Angeles and San Francisco International Airports. Safety, cost, and fuel savings associated with strategy implementation were also examined.

Two strategies, aircraft towing and shutdown of one engine during taxi operations, provided significant emission reduction. However, there are a number of safety problems associated with aircraft towing. The shutdown of one engine while taxiing was found to be the most viable strategy because of substantial emission reductions, cost benefits resulting from fuel savings, and no apparent safety problems.

THE REDUCTION OF AIR POLLUTANT EMISSIONS AT MAJOR AIRPORTS has been an area of concern for many regulatory agencies responsible for developing strategies to achieve cleaner air. The control of aircraft emissions has received considerable attention as a potential means of reducing airport-related emissions. However, the major focus has been on controlling emission rates from aircraft engines, which has resulted from the requirements of the Clean Air Act Amendments of 1970 (1).**

Recently, the California Air Resources Board funded a study to evaluate potential strategies to reduce aircraft emissions beyond the degree of control obtained from federal regulation of engine emissions (2). The primary objective was to determine reductions which could be achieved by controlling aircraft ground operations at Los Angeles International Airport (LAX) and San Francisco International Airport (SFO). Safety, cost, and fuel savings associated with the implementation of these strategies were also examined, to evaluate the viability of a strategy. This paper summarizes the major findings and methodology of the study.

*Mr. Gelinas performed the work discussed in this paper while employed with AeroVironment, Inc. in Pasadena, California.

**Numbers in parentheses designate References at end of paper.

AIRCRAFT OPERATIONS

Aircraft operations considered in the study included commercial-passenger, commercial-cargo, and general aviation. Table 1 shows the distribution of average day current operations by aircraft type at LAX and SFO. The types of aircraft operational modes included departure (idle, taxi, takeoff) and arrival (idle, taxi, and landing).

Table 1 - Distribution of Average Day Operations by Aircraft Type

Aircraft Type	Number of Aircraft Operations LAX	SFO
Commercial-Passenger		
B-747	54	34
DC-10	108	38
L-1011	50	24
B-707	118	86
DC-8	46	46
B-727	368	282
B-737	78	90
DC-9	56	48
Commuter	204	92
Commercial-Cargo		
B-747	36	20
DC-10	36	20
General Aviation		
Jet	118	10
Prop	173	134

The runway and terminal configurations of LAX and SFO are shown in Figures 1 and 2. LAX has two

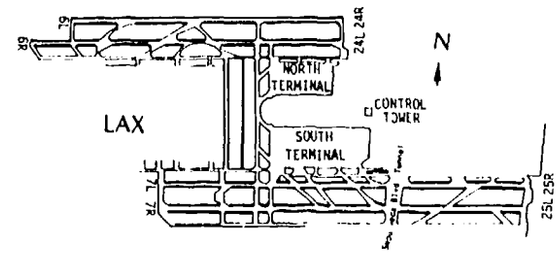


Fig. 1 - Runway and terminal configuration at LAX

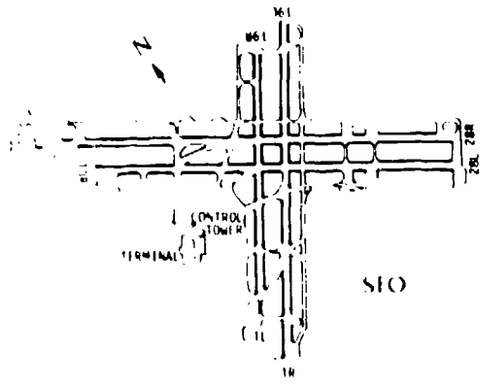


Fig. 2 - Runway and terminal configuration at SFO

pairs of parallel independent runways: the north runways (6R-24L and 6L-24R); and the south runways (7R-25L and 7L-25R). SFO has two pairs of intersecting runways: runways 10R-28L and 10L-28R; and runways 1L-19R and 1R-19L. At LAX, runways 24L/R and 25L/R are the predominant runways which are used about 98 percent of the time for arrivals and departures to the west. At SFO, runways 28L/R and 1L/R are used for arrivals and departures, respectively, about 67 percent of the time, while runways 28L/R are used for both arrivals and departures about 25 percent of the time. Runway useages were used to develop data on delay (or time spent in idle mode) and taxi distances.

BASELINE AIRCRAFT EMISSIONS AND FUEL USE

Both emissions and fuel use were estimated for each mode of operation and each type of aircraft for an average day of the year. Three pollutants were considered in this paper: carbon monoxide (CO); total hydrocarbons (THC); and oxides of nitrogen (NO_x). The following information were used to estimate emissions and fuel use: number of engines for each aircraft type; number of daily operations for each aircraft type; time spent in each operation mode; and emission and fuel use factors for each mode and aircraft type.

Taxi times between the terminal and runways were developed for a typical aircraft arriv'ng and departing during an average day. These times were estimated for each terminal using measured travel distances and average taxi speed and then weighted by number of operations to determine the average time. Idle times were estimated from delay/demand/capacity relationships (3). The amount of time spent in pushing back from the gate during departure was added to the departure idle time.

Data on daily aircraft operations were obtained from the Federal Aviation Administration air traffic control tower records at LAX and SFO. Modal emission and fuel use factors were obtained from a recently published EPA technical report on aircraft emission factors (4).

Table 2 shows the resulting average day aircraft emissions and fuel use for the baseline case (without strategies). The most significant percentage contribution of CO and THC emissions results from the idle and taxi modes.

Table 2 - Average Day Aircraft Emissions and Fuel Use for Baseline Case

Operational Mode	Emissions (tons/day) CO LAX	CO SFO	THC LAX	THC SFO	NO_x LAX	NO_x SFO	Fuel Use (10^3 gal/day) LAX	Fuel Use (10^3 gal/day) SFO
Departure								
Idle	1.2	2.7	1.7	1.6	0.2	0.1	15.0	12.9
Taxi	1.2	2.1	1.6	1.2	0.2	0.1	16.1	9.7
Takeoff	0.5	0.4	negl.	negl.	4.2	2.4	50.0	31.2
Arrival								
Idle	1.2	1.4	0.6	0.8	0.1	0.1	5.6	6.5
Taxi	4.1	1.4	2.1	0.8	0.2	0.1	20.0	6.5
Landing	1.0	0.6	0.4	0.2	1.3	0.6	19.8	10.9
Total	13.2	8.6	6.4	4.6	6.2	3.4	126.7	77.7

For NO_x, the takeoff mode has the largest contribution. Fuel use appears highest during takeoff, as would be expected. Also, departure idle fuel use appears to be higher than arrival idle fuel use. This is due to the longer delay time when waiting to takeoff.

STRATEGY EVALUATION

Four strategies,*** which appear to be potentially viable measures for reducing aircraft emissions, were evaluated. They are: tow aircraft between runways and terminal gates; shutdown one engine during taxi operations; control the time of departure; and assign aircraft to those runways which minimize the taxi distance between the gate and runway. The first two strategies have been analyzed in previous work (5).

For towing aircraft at LAX, both arrival and departure aircraft were considered. Taxi routes were identified for towing, since it was assumed that towing would not be implemented over short distances. At SFO, only departures were considered since arrivals turn off the runway a short distance from the terminal gates. Also, it was assumed that tractors currently being used would continue to be used for this type of towing. These emissions and fuel use from the tow tractors were subtracted from the aircraft reductions to determine the actual savings.

The strategy to shutdown one engine was assumed to apply to all commercial-passenger and cargo aircraft. In order to attain the same taxi speed that is normally accomplished with all engines operating, these aircraft must operate their remaining engines at a higher power setting. Changes in power settings affect the engine emission rate. Data for the JT3D engine (type used by B-727) were used to adjust aircraft emission rates and obtain new emission and fuel use factors for each aircraft type. These new factors and the exclusion of one

***A number of other strategies were considered in the study and were found to be less viable than the four strategies presented in this paper.

engine were used to estimate new idle and taxi emissions and fuel use.

The strategy to control departure time would reduce delay during the peak departure period by minimizing the time aircraft spend idling in a queue. Various techniques, such as, gate holds and sequencing aircraft departures would be used. Emissions and fuel use were estimated for the peak departure periods. It was determined that this strategy would reduce delay during this period by about one-half. Therefore, savings amounted to one-half of the peak period values.

The assignment of departing aircraft to runways was determined not to be applicable to SFO. This was due to the location of the runways relative to the terminal. For this strategy to be effective at LAX, the strengthening of the Sepulveda Blvd., tunnel, over which the south runways are built, would be required. Under existing conditions, takeoff and landing on the south runways are restricted to aircraft weighing more than 325,000 pounds. This strategy would change the number and mix of aircraft on both the north and south runways at LAX. The emissions and fuel use resulting from this new distribution of operations were compared to the baseline case to determine the savings.

No apparent safety problems or adverse cost impacts would be associated with the shutdown of one engine and the control of departure time. Although no apparent safety problems would result from the assignment of runways, the high cost of the south runway reconstruction would result in adverse cost impact. However, some of this construction cost would be offset by a savings in fuel cost.

A number of safety problems are associated with aircraft towing. Examples of these problems are: reliability of the nose gear under continual stress of long-distance towing; difficulty in engine startup under adverse wind conditions; and adequate space near the runway for coupling and uncoupling aircraft to the tow tractor.

An estimation of the total costs required to implement towing of aircraft was not prepared. However, the resulting savings in annual fuel cost were estimated to be $5 million for LAX and $2 million for SFO.

SUMMARY AND CONCLUSIONS

Table 3 presents a summary of the percentage of emission reduction and fuel savings estimated for each strategy. (The results for each strategy should be considered separately and not combined or added.)

Table 3 - Summary of Emission Reductions and Fuel Savings Estimates

Strategy	Emission Reduction (%)						Fuel Savings (%)	
	CO		THC		NO_x			
	LAX	SFO	LAX	SFO	LAX	SFO	LAX	SFO
Tow Aircraft	48	35	52	40	5	4	28	18
Shutdown One Engine	27	28	33	33	(+2)	(+2)	3	3
Control Departure Time	5	4	5	4	1	1	2	2
Assign Runways	17	-	14	-	2	-	10	-

Two strategies, aircraft towing and shutdown of one engine, provided the most significant emission reductions (about 25 to 50 percent for CO and THC). However, the engine shutdown strategy could cause a slight increase in NO_x emissions. The strategy to assign runways provided a reduction of approximately 15 percent in CO and THC emissions at LAX. None of the strategies reduced NO_x emissions more than 5 percent. The strategy to control departure time did not provide a substantial reduction of emissions.

Although aircraft towing would have a number of associated safety problems, it provided a significant savings in fuel (about 20 to 30 percent). Assignment of runways at LAX could provide some fuel savings (10 percent), but the cost required for construction would be substantial.

The strategy to shutdown one engine while taxiing was found to be the most viable of the four strategies evaluated. It provided significant emission reductions with cost benefits resulting from a fuel savings and had no apparent safety problems.

The findings presented in this paper for LAX and SFO could be generalized to other major airports with similar runway and terminal configuration, number of aircraft operations, and types of aircraft.

ACKNOWLEDGEMENTS

The work presented in this paper was sponsored by the California Air Resources Board (ARB). Mr. Jack Paskind was the project officer for the ARB. He and his staff provided technical direction to the study. Their contributions are greatfully acknowledged. However, responsibility for the contents of this paper remains with the authors and do not necessarily reflect the opinions of the ARB.

REFERENCES

1. U.S. Congress, "Clean Air Act Amendments of 1970." Public Law 91-604, U.S. Government Printing Office, Washington, D.C., December 31, 1970.

2. G. Gelinas, "Evaluation of Emission Control Strategies for Airfield Operations at Los Angeles and San Francisco International Airports." AeroVironment, Inc., Pasadena, California, to be published.

3. U.S. Federal Aviation Administration, Advisor Circular AC 150/5060-4, Washington, D.C., April 1977.

4. R. Pace, "Technical Support Report on Aircraft Emission Factors." Unpublished, U.S. Environmental Protection Agency, Office of Mobile Source Air Pollution Control, Ann Arbor, Michigan, March 1977.

5. R. Cirillo, J. Tachanz, J. Canaioni, "An Evaluation of Strategies for Airport Air Pollution Control." Argonne National Laboratory, Report No. EPA-450/3-75-052, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, January 1975.

DISCUSSION

LINDENHOFEN: With regard to towing, did you calculate tractor emissions, and is that included in the reduction?

GELINAS: We did calculate emissions from the tractor during the towing and we subtracted that from the emission reductions that you attain from shutting down all the engines.

GOODMAN: I have three questions and one comment. I may have missed it on one of your slides, but how much taxi time with engines operating or idle time did you assume in both the baseline and the various strategy cases, particularly the towing, on the one-engine-shutdown cases?

GELINAS: The taxi time or the idle time, which one are you talking about?

GOODMAN: The sum of the two.

GELINAS: The taxi times, of course, were dependent on which terminal area you were leaving from, and taxi times ranged anywhere from one and a half minutes to somewhere in the order of nine minutes. Idle times on departure were effectively related to the capacity of the runway and the demand, the number of aircraft that were trying to take off, and that varied during the day. We estimated hour by hour.

GOODMAN: That was the baseline case. What about the towing and the one-engine-shutdown strategies?

GELINAS: We didn't really look at the time it would take for an aircraft to be towed. We didn't consider that. We did consider emission reduction during the taxi procedure, but we didn't look at the additional time required to get the airplane off the ground.

GOODMAN: How long did you assume that the engines operated after startup?

GELINAS: We did include a startup (or warmup) time of two minutes when they got to the end of the runway and turned on their engines. That was included in the idle time.

GOODMAN: I would just comment that about five minutes has commonly been assumed to be necessary for temperature stabilization and equalization throughout the engine. Otherwise, there could be a maintenance cost impact, which perhaps was not taken into account. I'm not sure that anybody has quantified it, but it must be considered.

GELINAS: I think we were told that two minutes was sufficient to warm up the engines, to start them up and warm them up.

GOODMAN: The second question I had was what towing speed did you assume, using existing tugs?

GELINAS: The tugs traveled at 15 miles per hour on the average, including the trip out towing an aircraft to the end of the runway, and then the return without an aircraft.

GOODMAN: Did you calculate the effects of the possible reduction in aircraft effective taxi speed on the total airport capacity at these peak periods?

GELINAS: No, we didn't look at that problem.

GOODMAN: The reason I asked the question is that, in consultation with airport authorities, we have assessed there would be quite a reduction in the capacity if you follow this procedure at a peak hour. That could be quite dramatic.

GELINAS: The scope of the study included some 19 strategies. Obviously we couldn't spend a lot of time looking at towing, so we made certain assumptions and we didn't get into any big capacity/delay/demand models to determine the effects of all these timing factors on the operations at the airports.

GOODMAN: That finishes the questions. My comment is that you seemed to have assumed that there were no safety aspects to do with remote startup. You have addressed the safety aspects of towing the airplane, the nose gear and so on, but we do have some concern about the need for extra precautions if you are going to start the aircraft engines up at remote points, especially at the beginning of the runways and so on. There is a need for fire protection equipment to be located there, and this could have quite a significant economic impact even if you overcome the safety aspects.

GELINAS: I think I did mention that there was a difficulty in engine startup at the end of the runway, and this was basically due to problems with adverse wind directions, depending on how the aircraft was facing.

GOODMAN: I got the impression you were talking about technical problems rather than safety problems.

GELINAS: Okay.

STUDY OF LAKE ERIE OFFSHORE SITE, CLEVELAND, OHIO

Robert C. Koch
Jonathan D. Cook

GEOMET, Incorporated
Gaithersburg, Maryland, U.S.A.

ABSTRACT

Air quality levels due to emissions from a proposed jetport in Lake Erie near Cleveland were evaluated for the year 2000 using a diffusion model for simulating airport operations. Contributions to air quality due to emissions from the jetport alone were found to be well below national standards at all locations investigated, including locations within the jetport itself, and negligible in comparison to concentrations due to non-airport sources at locations in the city of Cleveland.

A STUDY WAS UNDERTAKEN between May and August, 1976 to evaluate the impact on air quality of a proposed airport site, to be located offshore of Cleveland in Lake Erie. Existing air quality levels and projected air quality levels for the year 2000, with and without the proposed airport, were analyzed.

A preliminary analysis of air quality effects in the vicinity of the Cleveland lakeshore was made to select a site for more detailed evaluation (1)*. In this analysis the possible impact of an offshore airport on the nearby urban shore and the possible impact of urban pollution on the offshore airport were considered. Both conventional wind patterns and lake breeze cells were analyzed. It was concluded that if the airport were located six miles from the shoreline, there would be sufficient dilution of pollutants in travelling between the two locations to minimize the impact of either area on the other.

*Numbers in parentheses designate References at the end of the paper.

METHODOLOGY

Two models were used to estimate air quality levels. One model, the Sampled Chronological Input Model (SCIM), was used to estimate the effects of non-airport related emissions associated with industrial and transportation-generated emissions. The other model, the GEOMET Airport Model (GAM), was used to estimate the effects due to airport and airport-related emissions. Results from the two models were overlaid to obtain the resultant air quality from all sources. Special modifications were made to the outputs of these models to account for the influence of the lake breeze cell.

Non-Airport Sources

The Sampled Chronological Impact Model (SCIM) was used in this study to generate present and future baseline air quality estimates. This model generates statistical distributions of pollutant concentrations; has been extensively used and tested against other models and data; does not require calibration; and is on-line and ready for immediate implementation (2, 3, 4). SCIM is a regional air pollution simulation program, designed to provide the user with a method of estimating the air quality characteristics of a particular pollutant over a specified control area. Both the mean long-term concentration and the frequency distribution of short-term concentrations are estimated using conventional emission inventory and meteorological data.

The computer program calculates concentrations for a sample of short-term periods selected from a specified long-term period. The sample is then used to estimate the long-term mean concentration and the statistical frequency distribution of short-term concentrations. The expected annual maximum concentration is determined from the frequency distribution. The calculations are made for specified receptor locations.

The calculations are made using a multiple-source Gaussian plume model. In this study all emissions are represented as either area or point sources. Contributions from a given source to concentrations at a receptor are calculated using a numerical technique to evaluate the required integral equation. The "narrow plume" concept, which implies that crosswind variations in emission rates may be neglected, is an

important assumption in the numerical technique. This assumption is valid as long as the distance between variations in the area source emission rate is large compared to the crosswind diffusion parameter (σ_y). A critical characteristic of the numerical technique is the spacing of grid points for which emission rates per unit area are determined.

A significant feature of this program is that emissions which vary with time are lined to a chronology of weather observations, so that related variations in emission rates and in the dispersive capability of the atmosphere can be taken into account. In the emission algorithm used in this study emission rates are related to the hour of the day.

The program inputs are prepared from conveniently available emission data and standard weather data. The user controls the sample size by specifying the sampling interval between successive hours for which calculations are made. The standard program outputs consist of a data file containing the concentrations calculated for each specified location for each selected hour and a printed statistical summary of the air quality characteristics of each location and of all locations combined.

Airport-Related Sources

The GEOMET Airport Model (GAM) was used to generate the jetport contributions. This model was selected because it generates statistical distributions of pollutant concentrations; had been tested against other models and data; did not require calibration; and was on-line and ready for immediate implementation. GAM is a joint emissions model and steady-state Gaussian plume air quality model, and is applicable to a variety of types of problems in airport pollution, including analyses required for impact statements. The model represents a wide range of airport operations in terms of types of aircraft and diurnal variations in the intensity of aircraft operations. Related airport activities including automobile traffic, ground aircraft support, maintenance, and fuel handling are also treated.

Outputs from the model include not only estimates of air quality levels due to the airport activities but also hourly estimates of emissions associated with each type of airport operation.

The Lake Breeze Cell

As part of this study special consideration was given to the possible impact of the Lake Breeze Cell (LBC) on pollutant concentrations emitting from the proposed jetport. The concern has been that the LBC traps pollutants, thereby recirculating them and resulting in increased pollutant concentrations within the area covered by the cell. Based on a review of current literature, we made modifications to GAM calculations to evaluate the potential impact of the LBC on annual air quality measurements.

Optically tracked tetroons (constant volume superpressure balloons) confirm the helical trajectory of air within the lake breeze regime (5). From this observation technique, it is evident that pollutants leaving the shoreline may complete one full cycle by noon. Pollutants entrained in this circulation follow a path quite different from that expected from analysis of surface wind data alone. The lake breeze cells have the capability to partially recirculate pollutants over shoreline areas; however, it is estimated that less than 50 percent are recirculated (6). If the synoptic wind is perpendicular to the onshore flow, as is commonly the case in the Cleveland area, the distance between successive on shore paths, associated with an air trajectory, is likely to be 50 km or more. If the synoptic flow is nearly parallel to the onshore flow the on shore paths may be only a few kilometers apart. In this study we have used the following treatment to estimate the influence of return flows in which new pollutants are entrained with old pollutants.

Hourly meteorological data from the Burke-Lakefront Airport (located on Lake Erie east of Cleveland) was searched for days during Apr through September marked by strong insolat and lack of synoptic-scale frontal presence. These days were examined for a wind shift from a light gradient wind to a wind which originated from the lake (a sector measured clockwise from 270° to 40°). If these primary criteria were met, additional parameters such as dew-point, temperature, and visibility changes accompanying the wind shift were examined. The flow off the water with the passage of the Lake Breeze Front should result in an increase in dewpoint, a drop in temperature, and an initial improvement in visibility. The NOAA Daily Weather Maps were used to determine days on which the flow from the lake was due to synoptic-scale gradient conditions rather than because of the lake breeze phenomenon. Such days were eliminated as LBC candidates. Thus, based on the Burke-Lakefront Airport data, an inventory of possible LBC cases in which the cell at least penetrated the Cleveland shoreline was assembled for further analysis.

Possible lake breeze days were compared with the three-hourly observations recorded at Cleveland-Hopkins International Airport to determine if the lake breeze had penetrated 8 km inland. Cases in which the lake breeze existed at Burke-Lakefront but showed no evidence of existence at Cleveland-Hopkins were eliminated from further considerations.* Thirty-two days in the 1971 data set met these criteria and the starting and ending hour of the lake breeze was noted for each day. A total of 158 hours (5.4 percent) were characterized by a lake breeze out of a data sample used for modeling consisting of 2928 hours (122 days).

The airport model was run with and without the LBC being considered. For the LBC run the calculated concentrations were multiplied by a factor of 1.5 for the particular hours when the LBC existed to simulate the recirculation of up to 50 percent of the pollutants in shoreline areas.

*Eleven days were eliminated on this basis.

DATA

Non-Airport Emissions

A summary of present and projected emissions used in this study by county is given in Table 1. The 151 major point sources emitting more than 100 tons per year of particulate, carbon monoxide, hydrocarbons, or nitrogen oxides were modeled as point sources in Cuyahoga County in the following way:

1. Total emissions from major point sources were subtracted from Cuyahoga County totals to obtain emissions to be distributed to area grids.
2. From the current National Emissions Data System (NEDS) inventory, emissions within Cuyahoga County were broken down by type of source. Types considered were major point sources, other point sources, ground transportation, and all other. Table 2 gives the resulting distribution for each pollutant.
3. The emissions component "point associated" was distributed evenly over grids judged to be industrial in nature. These were grids which contained at least one major point source.
4. Data were obtained from the Ohio Department of Transportation summarizing traffic count data throughout Cuyahoga County. Based on these data, estimates were made of vehicle miles travelled within each square grid.
5. Based on the figures derived in (4), ground transportation emissions were allocated to grids.
6. Finally, "all other area" is generally small compared to county total emissions, were allocated to grids on an equal area basis.

The resulting gridded area source file contained 400 square grids of dimension 2.5 kilometers, 110 grids of dimension 5 kilometers, and 110 grids of dimension 10 kilometers. Estimates for other counties and for future emissions were allocated from county to grid estimates in a similar manner.

Jetport Emissions

Jetport emissions were projected by GAM based on operational data. Spatial distribution of emissions from the airport is evaluated by GAM based on the layout of runways, taxiways, airport terminals, fuel storage areas, and roadway systems. Three hundred ninety-three point sources were used to represent the spatial distribution of emissions from the jetport. Emission rates for these points were based on the operation data summarized in Tables 3 through 5.

Hydrocarbon emissions from the fuel storage area were estimated using standard EPA emission factors, annual fuel throughput based on the number of flight operations, and expected flight times based on flight data for Cleveland Hopkins Airport. The total projected fuel consumption is 2.8×10^9 kilograms per year, and hydrocarbon emissions from fuel pumping operations are projected to be 1233 tons per year.

Potential sources of sulfur dioxide emissions from the jetport were found insignificant. The largest source is the heating plant which, based on use of fuel with .5% sulfur content, will have projected emissions of sulfur dioxide of 130 tons per year. In view of the distance of the proposed jetport from Cleveland, this was judged to be an insignificant source and was not modeled. As a result sulfur dioxide concentrations were not modeled either for baseline or for airport emissions.

Table 6 gives total projected emissions from the jetport on an annual basis. It is clear from the table that the largest source of emissions is ground operations - taxiing, idling at runway, etc. Ground transportation, primarily access to the airport from Cleveland, though small comparatively, is significant because of the closer proximity of much of the ground transportation emission, resulting from the access link from Cleveland to the jetport.

Meteorology

Meteorological data for input into the dispersion models was taken from the nearest meteorological observation station to the lake site zone, which is at the Burke Lakefront Airport, one mile northeast of downtown Cleveland. Data from 1971 was chosen to serve as input to the models, since from each parameter during 1971 conformed closest to the climatological norms for the Cleveland area among the four years that were tested (1970-1973). The Burke data is the most representative of meteorological conditions in the modeling region because of its proximity to the lake and to the area most significantly affected by pollutants from the proposed airport. The Burke station records ceiling height, wind velocity and wind direction for 18 hours per day. The six nighttime hours were estimated, based on the Cleveland-Hopkins Airport data. Mixing height data was provided by the Environmental Monitoring Unit of Case Western University.

The Burke-Lakefront meteorological data has certain limitations for its use to simulate conditions on the lake itself. The most prominent effect of Lake Erie on dispersion from a jetport located in the lake would be a reduction in dispersion, compared to that indicated by standard techniques, when the water temperature is much cooler than the inland air temperature. This situation would occur mostly during the daylight hours in spring and summer. An opposite situation may occur in winter when strong cold air advection occurs and the much warmer lake causes heating from below and consequently an unstable condition that may not be determined by the airport observations and standard techniques. The standard technique referred to is the determination of stability by hourly National Weather Service observations of cooling height, cloud cover, and wind speed. However, no data is available to better characterize the stability.

Air Quality Measurements

For this study 1975 measurements of particulate and NO_2 concentrations were obtained from the City of Cleveland's Division of Air Pollution Control. The data included particulate measurements at 22 locations in the City of Cleveland and 8 particulate measurements outside the city in Cuyahoga County. NO_2 was measured at 21 locations within the city. A summary of these measurements is given in Table 7. Of principal interest in this table is the fact that, although NO_2 air quality has not exceeded state and Federal standards anywhere in Cuyahoga County where it has been measured, the state standard for particulate air quality is exceeded almost everywhere.

To further illustrate the characteristics of the particulate concentrations in the Cleveland area, isopleths of annual mean concentrations are presented in Figure 1 (7). The highest concentrations are seen to occur in the south-central portion of the city. However, high concentrations (in excess of 75 $\mu g/m^3$) occur along the lake front from Lakewood to Bratenahl.

FINDINGS

In evaluating the impact of the proposed jetport on air quality, the following air quality measures were evaluated at nine selected receptor locations based on a full year of calculated concentration:

1. Maximum one hour carbon monoxide concentration;
2. Maximum eight hour carbon monoxide concentration;
3. Maximum 6 to 9 AM total hydrocarbons concentration;
4. Annual arithmetic average nitrogen oxides concentration;
5. Maximum 24 hour total suspended particulates concentration;
6. Annual geometric mean of hourly total suspended particulate concentrations.

The nine receptor locations for which air quality statistics were derived are shown in Figure 2. These nine receptor locations include seven in Cleveland itself, in areas most likely to be affected by pollutant concentrations from the jetport; they also include two at the jetport itself, one in the jetport parking area, and the other in the southwest area, where it is felt future airport services will develop.

Present Baseline Estimates

Table 8 gives results of computer modeling for the present baseline case. These estimates indicate that standards for total hydrocarbons, nitrogen oxides, and total suspended particulates are currently exceeded for several or all receptor locations. Air quality measures of total suspended particulates (published in 1976 by the Cleveland Division of Air Pollution Control), though somewhat lower than modeling estimates, are in reasonable agreement. For example, particulate measures at Station 21 indicate an annual geometric mean of 145 micrograms/m^3 and a 24-hour maximum of 335 micrograms/m^3. These measures are within the range of model estimates given in Table 8.

Estimates of mean annual nitrogen oxide concentrations, however, are consistently greater than observed values by about a factor of two. A number of factors can contribute to this discrepancy between modeled estimates and actual measurements. First, the model emission inventory corresponds to 1972, while the air quality measures were taken in 1975. Although it is not likely that actual emissions have decreased by a factor of two, it is possible that emission controls combined with improvements in emission inventorying techniques would result in a significantly lower estimated emission. Other factors which may contribute to the difference between modeled and observed concentrations are differences in the meteorologies of the modeled and observed years and, finally, the basic inaccuracies of computer modeling. The impact of this finding is that model estimates of background concentrations will be high in comparison to measured values.

Predicted Baseline Air Quality - The Year 2000

Table 9 gives predicted baseline air quality measurements for the year 2000. These results indicate that projected measures for carbon monoxide and total hydrocarbons are not exceeded at any station although annual nitrogen oxides and total suspended particulates are marginally exceeded at a few stations.

Impact of Proposed Jetport on Projected Air Quality

Model predictions of air quality measures resulting from the jetport alone are given in Table 10. These results indicate that pollutant concentrations from the proposed jetport are far below all standards at the nine receptor locations evaluated. Jetport concentrations at the seven receptor locations in Cleveland are generally negligible when compared with the appropriate air quality standard or projected baseline concentrations. Jetport concentrations at the two jetport jetport sites are considerably larger but still small compared to standards.

The impact of the Lake Breeze Cell in air quality measures was evaluated by increasing one hour concentrations by 50% during periods of definite LBC conditions. Air quality levels from airport emissions alone are shown in Table 11. It is clear from Table 11 that the impact of this adjustment is negligible.

Table 12 gives projected air quality measures due to both baseline and jetport concentrations. Air quality standards for NO_2 are slightly exceeded at three stations, while annual particulate standards are exceeded at four stations. In no case is the exceedance more than 20% of the standard. When compared with projected baseline air quality measures, the following findings are evident:

1. For all seven receptor locations in Cleveland, the impact of the jetport on air quality measures is negligible;

2. Although the jetport is the primary contributor to carbon monoxide measures at the two jetport receptors, the resulting measures are still well below national standards;
3. Similarly, although the jetport is a significant contributor to measures of total hydrocarbons, nitrogen oxides, and total suspended particulates at the two jetport receptors, the resulting measures are well below national standards.

Ozone concentrations were evaluated through the emission of hydrocarbons, since ozone reaches its highest buildup in the presence of hydrocarbon concentrations. Guidelines (8) for obtaining the national ozone standard (maximum 1-hour ozone concentration of 160 micrograms/m^3) requires a cutback in hydrocarbon emissions, when considered in the light of the maximum ozone concentration measurements for Cleveland. That cutback has been indicated to be approximately 85 percent of current emissions. Based on this, total hydrocarbon emissions should be reduced from 302,171 tons/year in 1972 to 47,758 tons/year in 2000. The hydrocarbon emissions projected to result from the jetport are 18.5 thousand tons per year. However, it is only through significantly increased hydrocarbon concentrations in the downtown Cleveland area that the ozone standard is likely to be significatnly affected by the jetport. Due to the distance of the proposed jetport from Cleveland itself, the model results show that the impact of the jetport on hydrocarbon concentrations in Cleveland is negligible. In no case does the jetport result in more than a one percent increase in the maximum six to nine AM hydrocarbon concentration. Hence we conclude that, despite the significant increase in hydrocarbon emissions due to the proposed jetport, that the jetport is not likely to have a significant impact on ozone concentrations due to its separation from Cleveland.

CONCLUSIONS

The major findings of this study may be summarized as follows:

1. Predicted background concentrations in the year 2000 were generally at or below national air quality standards. For three stations the nitrogen oxides standard was slightly exceeded; for four stations the annual particulate standard was also exceeded. In no case was the exceedance more than twenty percent greater than the standard.
2. Pollutant concentrations due to the jetport alone were well below national standards at all receptor locations, including those at the jetport itself.
3. The impact of the Lake Breeze Cell on air quality measures was negligible, despite the assumption of high impact on many individual one-hour concentrations.
4. Finally, the contribution of jetport emissions to air quality measures was negligible compared to projected concentrations from non-airport sources at the seven receptor locations in Cleveland. Air quality measures at the two jetport receptors were well below the national standards.

In summary, this study concludes that the proposed jetport would have little detrimental impact on the air quality in Cleveland.

REFERENCES

1. Howard Needles Tammen & Bergendoff, "Investigation of Lake Site Alternative Concepts", LERTA Final Report No. 12-1.

2. R.C. Koch and S.D. Thayer, "Validation and and Sensitivity Analysis of the Gaussian Plume Multiple-Source Urban Diffusion Model," Prepared for the Environmental Protection Agency, GEOMET Report Number EF-60, November, 1971.

3. R.C. Koch and Fisher, "Evaluation of the Multiple-Source Gaussian Plume Diffusion Model," Prepared for the Environmental Protection Agency, GEOMET Report Number EF-186, April 1973.

4. R.C. Koch and G.H. Stadkslev, "A User's Manual for the Sampled Chronological Impact Model (SCIM)," Prepared for the Environmental Protection Agency, GEOMET Report No. E-261, August 1973.

5. W.A. Lyons and L.E. Olsson, "Mesoscale Air Pollution Transport in the Chicago Lake Breeze," Journal of the Air Pollution Control Association, November 1972.

6. Personal communication with Walter A. Lyons, Mesomet, Inc., Chicago 1976.

7. "Annual Report" of the City of Cleveland Division of Air Pollution Control, 1976.

8. Federal Register, Appendix J, Volume 36, Number 228, 1971.

Table 1. SUMMARY OF PROJECTED 2000 EMISSIONS FOR COUNTIES WHOSE EMISSIONS WHOLLY OR PARTIALLY AFFECT AIR QUALITY AT THE TWO CANDIDATE SITES (PRESENT IN PARENTHESES)

Pollutant/ County	Emissions, Tons per Year			
	CO	HC	NO_x	Particulates
Cuyahoga	137,167(632,500)	26,207(180,602)	61,758(97,067)	40,843(121,059)
Lorain	19,564(97,283)	4,088(22,622)	11,023(12,597)	6,132(13,110)
Medina	9,089(36,504)	1,716(8,302)	4,088(4,661)	1,361(2,902)
Ashland	3,614(20,038)	730(4,438)	1,971(2,577)	584(1,155)
Wayne	8,140(41,339)	1,767(9,250)	4,198(5,482)	1,898(3,900)
Richland	11,972(69,849)	2,409(14,197)	8,760(9,499)	3,102(6,560)
Summit	50,626(212,099)	9,819(56,987)	21,827(27,205)	13,359(43,549)
Huron	5,293(25,964)	1,022(5,773)	2,602(3,315)	1,040(2,179)
Totals	245,465(1,135,576)	47,758(302,171)	116,227(162,403)	68,319(193,414)

Table 2. SUMMARY OF EMISSIONS REDISTRIBUTED IN CUYAHOGA COUNTY BY METHOD OF DISTRIBUTION (PRESENT EMISSIONS ONLY)

Method of Distribution	Pollutant			
	Carbon Monoxide	Total Suspended Particulate	Total Hydrocarbons	Nitrogen Oxides
1. Major Point Sources	150737	58084	12117	33768
2. Distributed As Area Sources	481763	62975	168485	63299
2a. Point Associated	0	54194	4726	10974
2b. Transportation	450762	2808	87498	42885
2c. Other Area	31001	5973	76261	9440

Table 3. Projected Annual and Design Hour Aircraft Operations for the Year 2000 for a Site in Lake Erie

Annual Operations (000's)	390
Design Hour Operations	98

Table 4. Design Hour Fleet Mix for the Year 2000 for a Site in Lake Erie

Class	Number	Percent of Total*
AA	35	36
A**	-	-
B	41	42
C	9	9
D & E	13	13

* Annual percent breakdown of fleet mix can be assumed identical to design hour percent breakdown.

** Class A aircraft are assumed to be negligible by 1990 and phased out by 2000.

Table 5. Vehicle Trips by Mode to Onshore and Offshore Facilities for the Year 2000

Onshore			Offshore		
	Vehicle Trips			Vehicle Trips	
Mode	Annual	Design Hour	Mode	Annual	Design Hour
Regional Rail (cars)	150	25	Regional Rail	181	33
Transit Bus	38	13	Auto Parking (cars being parked)	5,405	2,545
			Auto Drop-off	2,184	992
			Airport Bus/Limousine	103	16
			Taxi	323	120
			Trucks		

Note:

Annual trips are in thousands.
All trips are one-way.
Trucks do not use onshore facility in any concept.

Table 6. ESTIMATED ANNUAL EMISSIONS FROM JETPORT
TONS PER YEAR

Source	Pollutant			
	Carbon Monoxide	Total Hydrocarbons	Nitrogen Oxides	Total Suspended Particulate
Aircraft				
Ground Operations	32158	17059	4179	215
Flight Operations	469	36	3170	91
Fuel Storage	0	1233	0	0
Ground Transportation	1014	143	354	70
Total Airport Associated Emissions	33641	18471	7703	376

Table 7. Summary of Cleveland Air Quality Measurements for 1975

Pollutant	Type of Measurement	Highest Measurement (g/m^3)	National Standard (g/m^3)	State Standard (g/m^3)	Number of Measurements Which Exceeded State Standard
Particulate	Annual geometric mean	173	75	60	27 (30)*
	2nd highest 24-hour average	393	260	150	19 (30)
Nitrogen dioxide	Annual mean	84	100	100	0 (21)

* Number in parentheses is total number of measurements.

Table 8 ESTIMATED PRESENT AIR QUALITY AT SELECTED LOCATIONS

Receptor Location	Pollutant Concentration					
	Carbon Monoxide		Total Hydrocarbons	Nitrogen Oxides	Total Suspended Particulate	
	Maximum 1 Hour (mg/m^3)	Maximum 8 Hour (mg/m^3)	Maximum 6-9 AM ($\mu g/m^3$)	Annual Arithmetic Average ($\mu g/m^3$)	Maximum 24 Hour ($\mu g/m^3$)	Annual Geometric Mean ($\mu g/m^3$)
1 Superior Ave. and 55th St.	14.6	5.7	1049	140	483	141
2 Municipal Stadium	12.0	5.4	1007	136	588	162
3 Edgewater Park	10.1	4.8	984	101	477	120
4 Gordon Park	15.8	5.4	1075	159	537	175
5 Bratenahl	17.2	5.3	1040	116	397	91
6 Euclid and E. 9th Sts.	13.7	5.7	1012	158	625	194
7 Court House	12.7	5.6	1011	148	576	170
8 Jetport -- NE	6.8	2.6	766	52	368	64
9 Jetport -- SW	6.8	2.6	747	50	354	63
National Standard	40	10	160	100	260	75

Table 9 PREDICTED AIR QUALITY DUE TO BACKGROUND EMISSIONS ALONE YEAR 2000

Receptor Location	Pollutant Concentration					
	Carbon Monoxide		Total Hydrocarbons	Nitrogen Oxides	Total Suspended Particulate	
	Maximum 1 Hour (mg/m^3)	Maximum 8 Hour (mg/m^3)	Maximum 6-9 AM ($\mu g/m^3$)	Annual Arithmetic Average ($\mu g/m^3$)	Maximum 24 Hour ($\mu g/m^3$)	Annual Geometric Mean ($\mu g/m^3$)
1 Superior Ave. and 55th St.	3.1	1.0	134	95	193	71
2 Municipal Stadium	2.3	0.9	133	91	216	79
3 Edgewater Park	1.8	0.8	139	69	181	65
4 Gordon Park	3.2	1.0	138	103	211	82
5 Bratenahl	3.5	1.1	140	81	169	57
6 Euclid and E. 9th Sts.	2.8	1.0	132	107	232	88
7 Court House	2.6	1.0	133	99	214	81
8 Jetport -- NE	1.8	0.5	103	40	158	47
9 Jetport -- SW	1.6	0.6	105	38	153	46
National Standard	40	10	160	100	260	75

Table 10 PREDICTED AIR QUALITY DUE TO JETPORT ALONE
(Without Lake Breeze Cell Adjustment)
YEAR 2000

Receptor Location	Pollutant Concentration					
	Carbon Monoxide		Total Hydrocarbons	Nitrogen Oxides	Total Suspended Particulate	
	Maximum 1 Hour (mg/m^3)	Maximum 8 Hour (mg/m^3)	Maximum 6-9 AM ($\mu g/m^3$)	Annual Arithmetic Average ($\mu g/m^3$)	Maximum 24 Hour ($\mu g/m^3$)	Annual Geometric Mean* ($\mu g/m^3$)
1 Superior Ave. and 55th St.	0.25	0.13	4.5	1.837	2.387	0.288
2 Municipal Stadium	0.94	0.38	45.8	1.804	3.120	0.252
3 Edgewater Park	0.25	0.08	12.1	0.860	0.729	0.124
4 Gordon Park	0.31	0.11	25.8	1.949	1.413	0.291
5 Bratenahl	0.58	0.14	3.9	1.326	0.608	0.157
6 Euclid and E. 9th Sts.	0.79	0.32	37.2	1.356	2.752	0.171
7 Court House	0.82	0.37	42.2	2.092	3.537	0.308
8 Jetport -- NE	10.19	2.46	64.0	47.497	16.305	4.444
9 Jetport -- SW	5.46	2.27	38.3	44.254	34.131	3.987
National Standard	40	10	160	100	260	75

*For computational purposes, the geometric mean was calculated assuming a background TSP concentration of 30 $\mu g/sec$. However the figures reported in this table have this background component subtracted from them.

Table 11 PREDICTED AIR QUALITY DUE TO JETPORT ALONE
(With Lake Breeze Cell Adjustment)
YEAR 2000

Receptor Location	Pollutant Concentration					
	Carbon Monoxide		Total Hydrocarbons	Nitrogen Oxides	Total Suspended Particulate	
	Maximum 1 Hour (mg/m^3)	Maximum 8 Hour (mg/m^3)	Maximum 6-9 AM ($\mu g/m^3$)	Annual Arithmetic Average ($\mu g/m^3$)	Maximum 24 Hour ($\mu g/m^3$)	Annual Geometric Mean* ($\mu g/m^3$)
1 Superior Ave. and 55th St.	0.25	0.13	4.5	1.837	2.387	0.288
2 Municipal Stadium	0.94	0.38	45.8	1.834	3.120	0.258
3 Edgewater Park	0.25	0.08	12.1	0.879	0.729	0.127
4 Gordon Park	0.31	0.11	25.8	1.949	1.413	0.291
5 Bratenahl	0.58	0.14	3.9	1.326	0.608	0.157
6 Euclid and E. 9th Sts.	0.79	0.32	37.2	1.366	2.752	0.173
7 Court House	0.82	0.37	42.2	2.147	3.537	0.318
8 Jetport -- NE	10.19	2.46	64.0	47.907	16.305	4.470
9 Jetport -- SW	5.46	2.27	38.3	44.863	34.592	4.031
National Standard	40	10	160	100	260	75

*For computational purposes, the geometric mean was calculated assuming a background TSP concentration of 30 $\mu g/sec$. However the figures reported in this table have this background component subtracted from them.

Table 12 PREDICTED AIR QUALITY DUE TO PROPOSED JETPORT AND PROJECTED BACKGROUND EMISSIONS YEAR 2000

Receptor Location	Pollutant Concentration					
	Carbon Monoxide		Total Hydrocarbons	Nitrogen Oxides	Total Suspended Particulate	
	Maximum 1 Hour (mg/m^3)	Maximum 8 Hour (mg/m^3)	Maximum 6-9 AM ($\mu g/m^3$)	Annual Arithmetic Average ($\mu g/m^3$)	Maximum 24 Hour ($\mu g/m^3$)	Annual Geometric Mean ($\mu g/m^3$)
1 Superior Ave. and 55th St.	3.1	1.0	134	97	193	72
2 Municipal Stadium	2.3	1.0	133	93	216	79
3 Edgewater Park	1.8	0.8	139	70	182	65
4 Gordon Park	3.2	1.0	139	105	211	82
5 Bratenahl	3.5	1.1	141	82	169	57
6 Euclid and E. 9th Sts.	2.8	1.1	132	108	233	88
7 Court House	2.5	1.0	133	101	214	81
8 Jetport -- NE	10.2	2.5	115	88	163	52
9 Jetport -- SW	6.3	2.6	126	83	187	50
National Standard	40	10	160	100	260	75

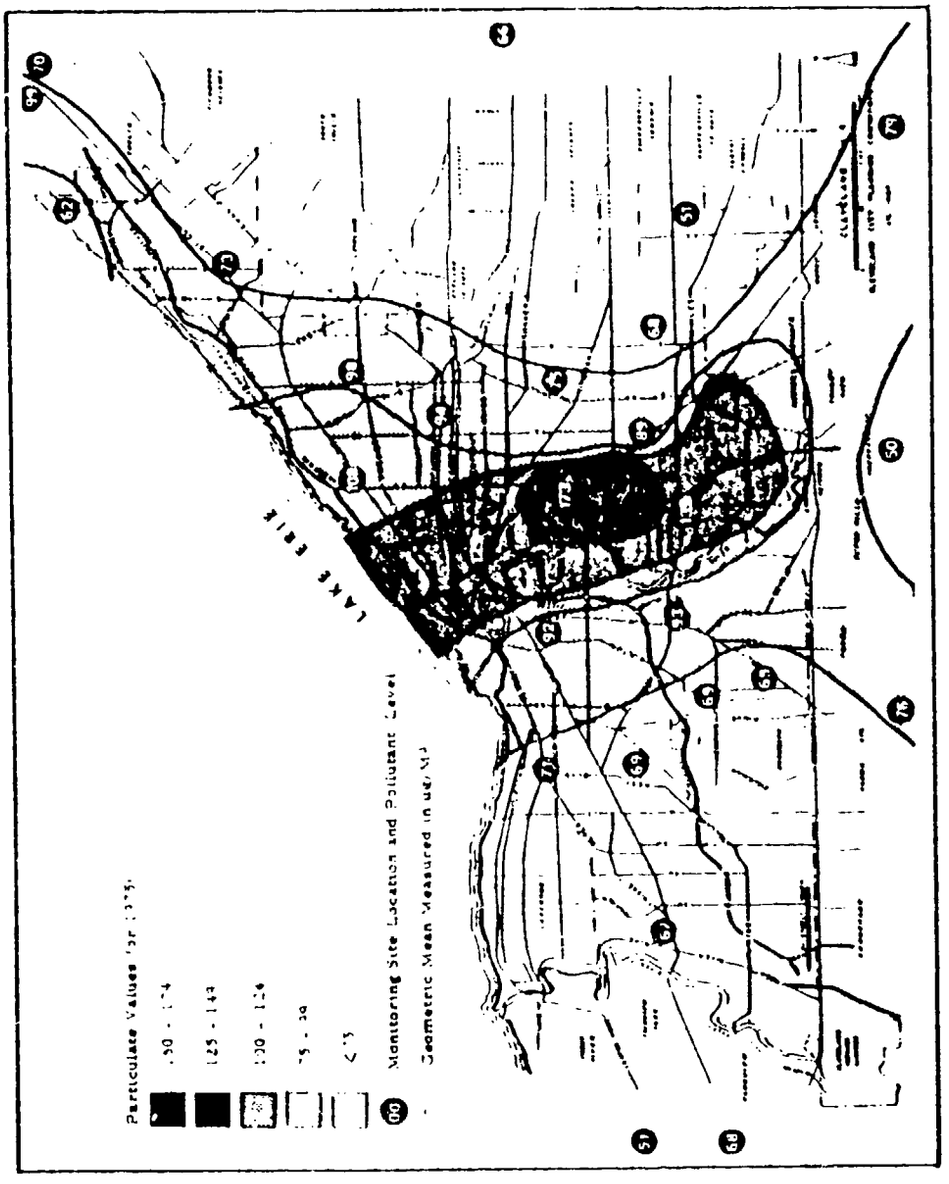


Figure 1 Annual Mean Concentrations of Particulate Measured in Cleveland During 1975

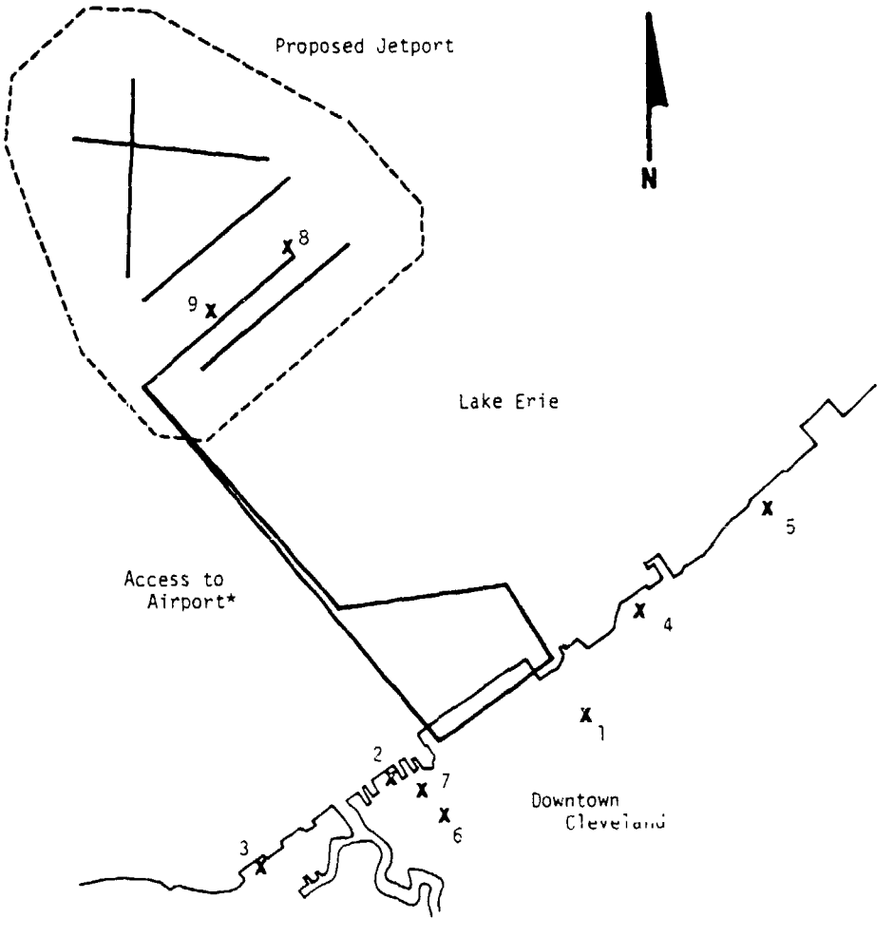


Figure 2. Receptor Locations Relative to Proposed Jetport and Cleveland Shoreline (Approximate Scale: 2.56 kilometers)

*For modeling purposes, approximated by a series of straight line segments.

DISCUSSION

YAMARTINO: You mentioned that you considered this helical path associated with the lake breeze cells, but then you also mentioned that it's a Gaussian plume.

I am just curious, how did you account for the transport over water? Did you put in a reduced and more stable situation, or just exactly what did you do?

KOCH: We had meteorological measurements from a station right on the shoreline there. There is a small airport just northeast of the city, and we used that to estimate the stability conditions in the Gaussian plume model. To the extent that they were reflected in the measurements at that station, they were included. That is how they would be included in the model.

COOK: We also had meteorological data directly from the lake.

KOCH: There was a site a mile or so off the shore where there was an automatic recording station. That also was used in the model estimate.

TAYLOR: Looking at the last three tables it is possible to compare predicted air quality due to background emissions, then predicted quality due to jetport alone, and then predicted quality due to the two together. It seems to me that at any given location, that should be quite additive, that is, you should be able to determine the predicted value for jetport and background from adding jetport plus background.

Looking at hydrocarbons, which seem to be the most significant and easiest to check, if you take, for instance, location two at the municipal stadium, there is a 133 due to background emissions alone, predicted jetport contribution is 45.8, but the total is only 133 again.

KOCH: The reason for that is the two maximum heights don't occur at the same time. They were paired together. In other words, once you add the two fields for the full year, you get a maximum which is probably not the sum of the two maximums.

TAYLOR: It hasn't changed. Is that because the maximum was completed?

KOCH: It probably was. That would be the reason there would be different data. In that case, it would have been the highest maximum from one or the other.

TAYLOR: And so it happens they just don't coincide because actually it is the same figure, exactly the same figure?

KOCH: That's right. They don't coincide at all. There is probably no contribution from the airport during the period that the maximum occurred.

COOK: Did you look at the annual means? You will notice that they do add up.

KOCH: But the maximum hourly short-term contributions would not necessarily be additive.

SEGAL: On the maximum case you listed there, could you indicate what the wind speed was and the stability class?

COOK: I don't know.

SEGAL: The second thing is what meteorological information did you use to get the sigmas?

KOCH: It was cloud cover and wind speed to determine atmospheric stability, and then we used the Pasquill-Gifford dispersion parameters.

DALEY: It seems to me that the extremely stable air over the lake would cause potentially very high concentrations under a lot of conditions, particularly in the spring.

Many of us have seen the classic photos of lake steamers from Chicago and across from Milwaukee. You can see plumes that persist for hours essentially under molecular diffusion.

KOCH: It's true that the model was based on the standard Pasquill-Gifford dispersion parameters. If, in fact, that underestimates or allows too much dispersion in the various stability conditions, then that effect would not be reflected in our model. We didn't have any other data on which to estimate how limited that could be under various stability conditions.

AIRPORT INFORMATION FILE FOR ANALYSIS AND MODELING

David E. Winer, Office of Environment and Energy
Carlton Wine, Office of Aviation Policy

Federal Aviation Administration
Washington, D.C.

ABSTRACT

An extensive data set concerning approximately 1500 U.S. airports is assembled from numerous sources into a single file accessible by computer. The data are selected particularly for their relevance to studies concerning environmental protection and energy conservation but have other possible application. Types of information include physical descriptions of the airports, breakdowns of operations by airplane class and time of day, demographics, and use restrictions of environmental interest. Principal uses of the file are as input data to mathematical models, data to be sorted and tested in answer to a variety of queries, information for reference listings, and material for research studies. A user's manual, planned for 1979, will describe fully the contents of the file and how it can be accessed.

WE DID NOT REALIZE AT THE INCEPTION of the data base which developed into the Airport Information File (AIF) how useful it would become. Indeed, we wished only to solve an immediate problem requiring voluminous data from several sources. The central need was for breakdowns of flight operations by types of airplanes. No single file existed which contained such data for both general aviation and air carriers. Examination of other items of information contained in the sources of operations data showed that there was more useful information which could be sorted out and merged into the file being created as input to an airport noise computation model. The file was unique--a single repository of flight operations data at U.S. airports whose activity could possibly be of concern for environmental assessment. Soon, a policy analysis problem caused us to add more data to this file. At the time it was used only by a small group of analysts. The success of the inquiries quickly led to requirements for new types of data so that more comprehensive studies could be carried out. The relative ease, rapidity, and low cost of compiling data into reports was recognized by analysts and managers alike. Encouraged by this experience, a more formal project emerged: to create a comprehensive collection of airport data and a system of adding to and organizing the computer file structure so that future mathematical modeling and analytical studies would be enhanced.

As will be shown, the existence of this file creates opportunities to investigate many interesting but otherwise obscure relations among the data, perhaps in areas beyond those of only environmental interest.

If necessary for a particular study, data from other sources could be merged into the AIF. One of the largest sources is the U.S. Department of Commerce which maintains extensive data bases of possible concern. For instance, the Census of Manufactures lists by Standard Metropolitan Statistical Areas such data as number of employees and value added by manufacturing. This information is available on computer tape through the Bureau of the Census Data User Service.

Although all information is retained on a computer disc-pac, the file structure in effect is similar to that of a standard office filing cabinet. In a figurative sense, there is a file "folder" for each airport arranged under the heading of the abbreviation for the airport. Each airport file contains all items of information currently listed except for missing or nonapplicable data. To date, the file has been interrogated for reports generation through two data base management languages: INQUIRE and EASYTRIEVE. Computations and modeling using the file have been accomplished with FORTRAN through creation of intermediate files from the AIF.

Each data element is assigned an alphanumeric code name consisting of up to eight characters which have been assigned with intent to make the name mnemonic. For example, the file name for the number of paved runways is HARDRNY, for the number of general aviation operations is GAOPS, for the FAA region is FAARGN, etc. At present there are no restrictions on the length of the alphanumeric field for data contained in each data element. The file now holds about two million alphanumeric characters but will be expanded as new information is needed. Each airport now requires about 1300 alphanumeric characters in its dossier.

FILE CONTENTS

Since the file is intended for multiple uses, several families of airport data are included. These are: (1) Physical Description; (2) Flight Operations Activity; (3) Demography; (4) Geography; (5) Administrative Information; (6) Airport Use Restrictions and Environmental Conditions; (7) Climate (planned); (8) Forecasts (planned); and (9) Air Quality (planned). A current file improvement project will result in many new data fields by 1979, but at present the following is a list of all data elements contained in the AIF.

Site Number
Airport Location ID
Associated City
State Associated City In
Nearest City
County Airport In
State Airport In
EPA State Code
EPA County Code
EPA Region Code
EPA Air Quality Control Region
Airport Owner
Publicly or Privately Owned
Miles and Direction from Associated City
Airport Latitude
Airport Longitude
Airport Elevation
Airport Acreage
Airport Square Miles
Jet Fuel for Sale to Public
FAR 139 CFR Index
Tower at Airport
Number of Hard Surface Runways
Number of GA Jet Runways
Longest Runway Length
Military Daily Operations
GA Daily Operations
GA Single Engine Prop Ops
GA Multi Engine Prop Ops
GA Turbo Prop Ops
GA Jet Ops
GA Jet Type A Ops
GA Jet Type B Ops
GA Jet Type C Ops
GA Jet Type D Ops
GA Jet Type E Ops
GA Jet Type F Ops
GA Jet Type G Ops
Day (0700-2159) Scheduled Ops
Night (2900-0659) Scheduled Ops
7 PM Day (0700-1859) Scheduled Ops
Evening (1900-2159) Scheduled Ops
Sum of Scheduled Ops
Day Scheduled Jet Ops
Night Scheduled Jet Ops
7 PM Day Scheduled Jet Ops
Evening Scheduled Jet Ops
Sum of Scheduled Jet Ops
U.S. Carrier US/US Ops
Foreign Carrier US/US Ops
U.S. Carrier Foreign/US Ops
Foreign Carrier Foreign/US Ops
U.S. Carrier US/US Jet Ops
Foreign Carrier US/US Jet Ops
U.S. Carrier Foreign/US Jet Ops
Foreign Carrier Foreign/US Jet Ops
2 Engine Narrow Body Day Ops
2 Engine Narrow Body Night Ops
2 Engine Narrow Body 7 PM Day Ops
2 Engine Narrow Body Evening Ops
3 Engine Narrow Body Day Ops
3 Engine Narrow Body Night Ops
3 Engine Narrow Body 7 PM Day Ops
3 Engine Narrow Body Evening Ops
4 Engine Narrow Body Day Ops
4 Engine Narrow Body Night Ops
4 Engine Narrow Body 7 PM Day Ops
4 Engine Narrow Body Evening Ops
2 Engine Narrow Body Day Ops
2 Engine Wide Body Night Ops
2 Engine Wide Body 7 PM Day Ops
2 Engine Wide Body Evening Ops
3 Engine Wide Body Day Ops
3 Engine Wide Body Night Ops
3 Engine Wide Body 7 PM Day Ops
3 Engine Wide Body Evening Ops
4 Engine Wide Body Day Ops
4 Engine Wide Body Night Ops
4 Engine Wide Body 7 PM Day Ops
4 Engine Wide Body Evening Ops
SST Day Ops
SST Night Ops
SST 7 PM Day Ops
SST Evening Ops
All Other Day Ops
All Other Night Ops
All Other 7 PM Day Ops
All Other Evening Ops
Total Jet Ops
Total Prop Ops
Total Turboprop Ops
Total Helicopter Ops
In Increments of 1 Mile up to 10 Miles (1970 Census)
- Total Population
- Number of Households in 1975
- Total Income
- Total Home Value
- Total Rent
- Average Income
- Average Home Value
- Average Rent
- Population Change
- Population Growth Rate
- Number of Families

FAA Region
FAA District
Time Zone
Weather Station
Joint Use for Military Aircraft
Based Aircraft Single Engine and Over 4 Places
Based Aircraft Single Engine 1 to 3 Places
Based Aircraft Multi Engine
Tower Status
Air Route Traffic Control Center
Landing Pattern Altitude
Number of IFR Runways
Cargo Flights Day
Cargo Flights Night
Cargo Flights 7 PM Day
Cargo Flights Evening
Number of Runways
Runway Heading
Runway Length
Surface Composition
Runway Threshold
Code Words for Airport Use Restrictions and Environmental Conditions

FILE STRUCTURE

This data base now includes approximately 1500 U.S. airports and is called the FAA Office of Environment and Energy Airport Information File. All air carrier airports are included (approximately 300). The original practice of extracting selected data from existing data bases

has continued, but in one important instance a wholly original file was created expressly for incorporation within the AIF. Often the desired data are synthesized or aggregated from the source files. For example the source airline scheduled operations data are listed by airplane type and model but are stored in the AIF by sums of operations of body types, e.g., 3-engine narrow body (3 ENB) and 4-engine wide body (4 EWB). Similarly, general aviation operations are derived by adding together local, itinerant, and air taxi operations. All operations data in the AIF are converted to daily operations from the original weekly or yearly source data.

Normally, new data are readily acquired from computer sources and merged into the AIF due to the existence of a common link--usually the three letter or number airport location identifier (LOCID). Each airport in the U.S. also has a unique FAA site number which can be used as the common link. Inclusion of the Environmental Protection Agency Air Quality Control Region number for each airport posed a special problem: the only common link between files was state and county. Manual intervention was required to achieve the proper assignment of airports to the correct region in about 20 instances. Similarly, addition of demographic data from the 1970 Census was made possible by existence in the file of the latitude/longitude coordinates of each airport. Such merging techniques offer the opportunity to include in the future other types of information which are not specifically airport related, but which are of interest.

The numeric data are stored in packed fields to minimize storage space. This condition has a significant drawback in that access to the file for report generation must be via data base management languages which can read packed data (such as INQUIRE and EASYTRIEVE). In order to use the file as input to models and analytical programs it is usually necessary to create a subfile which contains data elements of fixed word length. Current development efforts include restructuring to allow direct access by models and statistical programs written in FORTRAN such as the FAA Integrated Noise Model and the Statistical Package for the Social Sciences. This new file format will also allow access by almost any data base management language. Increased storage on computer disc-pac or other medium will be the consequence, but the large improvement in utility outweighs this factor.

SOURCES OF THE DATA

So far, all items in the file pertaining to physical description and location of airports have been acquired from the FAA National Flight Data Center Airport Master Records. That data base is also the source of the flight operations data from which we calculate and store general aviation daily operations in terms appropriate for environmental assessment. It should be noted that the source general aviation operation statistics are estimates. They are based on the best available combination of records and judgments supplied by airport officials and are reviewed by FAA officials. We have provided distributions by type of airplane of general aviation operations by combining total operations data with national survey results and with data from the FAA Census of U.S. Civil Aircraft. In effect, operations data at any one airport by type of general aviation airplane are estimates based on estimates and for analyses at individual airports may not be accurate enough for some purposes.

Operations of air carrier airplanes are traceable to actual airline scheduled data. These operations are at present aggregated from specific airplane models into generic body types and are listed by time blocks encountered in airport noise modeling. It would be possible to include distributions by other factors such as length of trip (as an indicator of fuel aboard and thus as a surrogate for weight) and by nominal engine types. There is a pending request for this level of detail.

The Environmental Protection Agency furnished the data concerning Air Quality Control Regions and their region, county, and state codes.

Demographic data for 1 mile incremental rings about airports are derived from the publicly available Bureau of the Census tapes. This was accomplished under contract with CACI, Inc., a firm which has developed an extensive system for extracting data from the census tapes and formatting into lists within desired geographical areas.

The information concerning airport use restrictions and local environmental conditions was obtained through a special survey of approximately 500 airports. This survey was conducted by the FAA Office of Environment and Energy with cooperation of all the FAA Regional Offices and was used first to create a separate computer file known as the Environmental Data Bank. Inclusion of this entire file within the AIF provides cross-access to much more airport-related data for its list of airports. As a means of compactly storing a large amount of information, these data are included in the file as alphanumeric code words. These must be recalled through a de-code listing in order to obtain verbal descriptions; e.g., "4D2" stands for "restriction on time of engine runup maintenance."

USES OF THE FILE

By virtue of its computer accessibility, this data base can be used in four principal ways: (1) automatic selection of data as input for mathematical models, (2) assembly of data for policy studies and special queries, (3) reference listings for often needed information, and (4) research. Of these uses the most frequent has been in the policy analysis area, but with planned additions the AIF will likely be used extensively for modeling of airport noise.

The FAA Integrated Noise Model requires all the following types of data which are or soon will be extractable from the file: present and projected operations by type of airplane by time by stage length, runway locations including dimensions and headings, annual average temperature and field elevation. It will still be necessary manually to determine flight tracks and runway utilization but it is possible even for these

matters to be determined by default algorithms when the resulting loss in accuracy is acceptable for the intended use of the model. It appears quite feasible to use the AIF as a source of data for other types of models such as those which compute air pollution and energy consumption but to date this has not been done.

As an example of the use of the file for special queries, Figure 1 is a listing prepared for the possible interest of the attendees of the 1978 SAE/APCA Conference on Air Quality and Aviation. Preparation of the computer query took a few minutes of an experienced programmer's time and cost $7.00 in computer charges. The type of report illustrated by Figure 1 is generated routinely since it requires only a listing of existing data under column headings. Considerably more complex reports are sometimes called for--those which require computations using the AIF data and listings of the computed results. The following examples are some of the actual queries which have been satisfied by interrogating the AIF: How many airports in each state have 4-engine narrow body operations? Which U.S. airports have curfews? What is the rank order of airports by JT8D-powered (2 and 3 engine narrow body) operations? How many people live within 5 miles of Midway and O'Hare airports? Based on number of operations and population, which airports in each FAA Region are the best candidates for a survey concerning environmental conditions?

Figure 2 is the first page of a typical listing which is useful as a basic reference for environmental work. This sample has the airports ranked by scheduled jet operations but this type of report is frequently also listed in alphabetical order for cross referencing.

EXAMPLE OF RESEARCH CAPABILITY

An illustration of the potential of the file for use in research is included in this paper as a methodological case study. The subject matter chosen deals with a question of interest to the FAA, one which has been under study by others using other methods. These materials were created expressly to demonstrate the wealth of information contained in the file and the adroitness with which one can extract, organize, and reveal relationships among the data, and further to test hypotheses concerning these relationships.

The question we chose to examine is suggested by a recent study by Nelson (1)*, which reports that aircraft noise has a statistically significant and negative effect on residential property values. That study discusses the price of land as a function of distance from airports, noting that two distinct effects operate simultaneously--depreciation due to noise, and appreciation due to accessibility and increased commercial value. (Nelson includes many other nonairport-related factors in his analysis.) In order to inspect the relation between home value and distance from an airport first in a broad overview, we selected the 100 busiest airports in the AIF, based on number of scheduled jet operations stored in the file. For each airport the average home value was then plotted as a point at each of 10 average distances from the airport. The mean of all values at each distance was also plotted. Figure 3 is the result.

SAMPLE REPORT FOR SAE/APCA CONFERENCE ON AIR QUALITY AND AVIATION — PAGE 1
AIRPORTS WITH ACTIVE AIR POLLUTION MONITORING SYSTEMS — 09/22/78

LOC ID	AIRPORT NAME	ASSOCIATED CITY	STATE	DAILY GA OPS	DAILY AC OPS	AQCR
SJC	SAN JOSE MUNI	SAN JOSE	CA	1074	198.4	030
PFN	PANAMA CITY-BAY COUNTY	PANAMA CITY	FL	316	30.0	005
PBI	PALM BEACH INTL	WEST PALM BEACH	FL	501	103.0	050
MCI	KANSAS CITY INTL	KANSAS CITY	MO	294	400.2	094
LAX	LOS ANGELES INTL	LOS ANGELES	CA	1565	1152.5	024
ISP	ISLIP MACARTHUR	ISLIP	NY	809	27.7	043
GYY	GARY MUNI	GARY	IN	149	0.0	067
CID	CEDAR RAPIDS MUNI	CEDAR RAPIDS	IA	226	47.7	088
BED	LAURENCE G HANSCOM FLD	BEDFORD	MA	727	7.1	119
ACY	NAFEC ATLANTIC CITY	ATLANTIC CITY	NJ	268	0.0	150

Fig. 1 - All airports in the AIF listed with air pollution monitoring systems installed. Other data are listed on the printout as an example of a special query: General Aviation Operations, Air Carrier Operations, and EPA Air Quality Control Region.

*Number in parentheses designates reference at end of paper.

9/20/78 — REFERENCE DATA FOR U.S. AIRPORTS (RANKED BY SCHEDULED JET OPERATIONS) FROM AEE AIRPORT INFORMATION FILE — PAGE 1

LOCID	CITY	ST	IN OX	UP CO	PU BX	J U	W X	RU NW	IF R	ARPT ACRES	SCHED JETOPS	NFOC RAMPS	NFOC MILUPS	CARGO OPS	DIST CITY	FIVE MILE RADIUS DEMOGRAPHICS TOTAL POP	GROWTH RATE	HOUSEHOLDS	AV HOME $
ORD	CHICAGO	IL	ES	1	PU	Y	Y	7	12	07000	1,407.0	264	10	44.2	16NW	281256	.35	92047	31003
ATL	ATLANTA	GA	DS	1	PU	N	Y	2	4	03300	1,260.2	148	3	1.0	06S	1482J2	2.57	53843	19364
LAX	LOS ANGELE	CA	ES	1	PU	Y	Y	5	8	03500	983.8	1565	13	33.5	10SW	816238	.66-	262504	30178
DFW	DALLAS-FOR	TX	ES	1	PU	N	Y	1		17520	827.0	178	1	13.7	14NW	23042	6.76	8738	20729
SFO	SAN FRANCI	CA	ES	1	PU	Y	Y	4	8	05207	678.7	197	14	22.2	09SE	1453318	.48-	511160	35240
DEN	DENVER	CO	DS	1	PU	N	Y	4	4	08600	672.2	231	4	9.5	09E	249287	1.09	91210	20356
JFK	NEW YORK	NY	ES	1	PU	N	Y	5	8	05200	649.0	149	2	61.6		6279J9	.29-	200525	27768
MIA	MIAMI	FL	ES	1	PU	N	Y	5	6	02699	610.4	218	3	20.6	09NW	420836	1.03	151715	18682
LGA	NEW YORK	NY	DS	1	PU	N	Y	3	6	00540	610.2	167	5	.0	05E	2279988	1.90-	832853	29708
DCA	WASHINGTON	DC	CS	1	PU	N	Y	3	5	00861	519.7	315	2	.0	03S	689985	1.61-	265613	25978
BOS	BOSTON	MA	ES	1	PU	N	Y	5	10	02364	519.2	319	3	8.6	04E	985903	2.05-	358879	20250
PIT	PITTSBURGH	PA	DS	1	PU	Y	Y	4	6	10000	508.5	363	41	.0	14NW	48880	1.70	16734	21653
STL	ST LOUIS	MO	DS	1	PU	Y	Y	3	3	02200	477.5	436	32	1.4	11NW	290232	.23-	86699	17807
IAH	HOUSTON	TX	DS	1	PU	N	Y	2	4	07200	426.5	228	1	4.9	17N	21561	15.91	11527	16109
DTW	DETROIT	MI	ES	1	PU	Y	Y	2	4	04800	417.2	239	1	11.5	17S	103872	1.98	32398	19062
MEM	MEMPHIS	TN	CS	1	PU	Y	Y	3	6	03056	399.7	879	14	1.4	04S	180319	1.11	64751	16375
PHL	PHILADELPH	PA	DS	1	PU	N	Y	3	6	02500	398.0	933	7	9.9	06SW	2866J4	1.18-	87724	18418
TPA	TAMPA	FL	DS	1	PU	N	Y	2	4	03300	380.2	248	1	.0	04W	162269	3.59	66173	19984
MSP	MINNEAPOLI	MN	ES	1	PU	Y	Y	2	3	02930	359.4	305	18	1.4	07SW	316781	3.89-	95583	22184
CLE	CLEVELAND	OH	DS	1	PU	N	Y	6	5	01492	346.7	667	3	5.4	10SW	202563	.29	92346	27238
EWR	NEWARK	NJ	ES	1	PU	N	Y	3	5	02167	337.5	212	2	9.2	03S	831922	1.74-	278522	22408
SEA	SEATTLE	WA	ES	1	PU	N	Y	2	4	02000	327.0	158	2	10.0	12S	151525	.45-	49927	23260
LAS	LAS VEGAS	NV	ES	1	PU	N	Y	1	2	01678	285.1	519	10	.0	08S	81020	5.49	31551	32472
MSY	NEW ORLEAN	LA	DS	1	PU	N	Y	3	6	01500	283.0	163	8	2.1	12W	141240	3.92	47992	23949
PHX	PHOENIX	AZ	ES	1	PU	Y	Y	2	4	01650	279.1	883	33	.0	03E	205723	1.98	98782	16270
HNL	HONOLULU	HI	ES	1	PU	Y	Y	4	3	04220	277.8	481	98	9.7	08W	175811	.98	47362	39983
MCI	KANSAS CIT	MO	CS	1	PU	N	Y	1	2	05000	246.7	294	2	1.4	17NW	417	.77	162	36583
FLL	FT LAUDERD	FL	DS	1	PU	N	N	3	5	01180	242.4	461	5	.0	09SW	143144	5.72	61642	29202
MCO	ORLANDO	FL	DS	1	PU	Y	Y	2	4	04624	233.5	16	3	1.0	07SE	36022	5.43	14703	21642
SAN	SAN DIEGO	CA	DS	1	PU	Y	Y	1	2	00460	220.1	338	27	.0	02W	323636	.68	123511	25327
BUF	BUFFALO	NY	CS	1	PU	N	Y	2	3	01000	219.0	186	7	.0	06E	297465	.43	99490	22182
PDX	PORTLAND	OR	DS	1	PU	Y	Y	3	6	03000	217.0	318	65	1.4	05NE	237049	1.28-	86203	16481
IND	INDIANAPOL	IN	CS	1	PU	N	Y	3	4	01800	214.7	347	9	1.4	08SW	76658	1.21	24439	18869
BAL	BALTIMORE	MD	ES	1	PU	N	Y	4	6	03731	213.7	384	15	6.2	10S	139127	1.57	45817	18163
SLC	SALT LAKE	UT	CS	1	PU	Y	Y	1	2	02767	202.5	965	34	.0	03W	49087	.18-	25088	18267
CVG	COVINGTON/	KY	DS	1	PU	N	Y	2	4	04072	201.7	180	3	.0	09SW	73853	2.51	23445	20252
MKE	MILWAUKEE	WI	DS	1	PU	Y	Y	5	6	01866	175.4	391	34	2.8	06S	252052	.02	88412	20624
BDL	WINDSOR LO	CT	DS	1	PU	Y	Y	3	6	02500	174.1	226	26	1.4	03W	38239	2.81	13096	25363
CLT	CHARLOTTE	NC	CS	1	PU	Y	Y	2	4	01300	168.2	333	18	.0	05W	98192	2.36	33821	15878
BNA	NASHVILLE	TN	CS	1	PU	N	Y	3	6	02300	165.5	436	24	.0	06SE	111703	1.65	38900	16044
SAT	SAN ANTONI	TX	CS	1	PU	N	N	4	8	02305	158.8	390	0	.0	08N	162721	4.01	45331	21425
CMH	COLUMBUS	OH	DS	1	PU	Y	Y	5	4	01600	157.5	758	8	.0	07E	220569	.34	72240	21076
SDF	LOUISVILLE	KY	CS	1	PU	Y	Y	2	4	01158	156.0	352	19	.0	05S	306053	.36	118511	15588
SJC	SAN JOSE	CA	CS	1	PU	N	N	3	4	01000	147.8	1078	2	.0	02NW	306924	1.21	117068	25029
DAY	DAYTON	OH	DS	1	PU	N	Y	3	6	03756	143.1	310	8	1.4	10N	33509	3.07	12088	22475
ROC	ROCHESTER	NY	CS	1	PU	N	Y	3	4	01063	142.2	720	0	.0	04SW	237365	1.34-	77835	19476
IAD	WASHINGTON	DC	ES	1	PU	N	Y	5	6	09966	141.1	260	0	.0	04NW	11453	5.03	4417	32043
OKC	OKLAHOMA C	OK	CS	1	PU	Y	Y	3	4	07250	140.5	243	26	.0	07SW	92270	1.59	33241	12831
ANC	ANCHORAGE	AK	ES	1	PU	N	Y	3	6	02374	137.4	389	12	24.1	05SW	49966	5.51	21343	35762
TUL	TULSA	OK	CS	1	PU	Y	Y	3	6	06000	135.7	550	19	.2	06NE	116107	1.59	44170	13475

Fig. 2 - One page from a listing compiled for reference purposes.

There appears to be by this method a lack of discernible relationship between the variables. As a rapid test to see if a relationship might be noticeable by excluding airports with fewer operations we re-ran the plot using only the 50 busiest airports. Somewhat surprisingly, the results were almost identical to those in which 100 airports were included.

Having dealt only with averages to this point, it seemed possible that strong relations might exist at some airports or at some types of airports but that the averaging process obliterates such trends. To test this hypothesis, we decided simply to plot the same variables as before by connecting the points to show trends at selected individual airports. In selecting airports for plotting, we compiled three lists: eight airports with relatively sparse population nearby, eight airports with relatively dense population nearby, and the same seven airports selected for the Nelson study. The AIF was used to compute a "population exposure index" as an attempt to place the first two lists in possibly significant separate classifications. Exposure index was defined as the product of number of jet operations times population living within 5 miles. This particular classification scheme did not, as we had expected, produce home value vs. distance curves with prominent characteristics unique to their exposure index category. In both high and low exposure index situations there were airports which showed both increasing and decreasing home value at the nearest distances. However, the seven airports selected in the Nelson study, taken as a class, did exhibit a characteristic trend--in six of seven cases the average home value declines near the airport. This set of curves is shown in Figure 4.

Due to the wide range of average home values at differing airport locations and the relatively small difference between the highest and lowest value at each particular airport, the trends in our plots such as those in Figure 4 were not readily apparent. With the end in mind of uncovering a nonobvious relationship, we replotted the same data after normalizing each point as a percent of maximum value at the airport. Figure 5 shows the group which did exhibit an overall tendency when plotted by this method, the eight airports with high exposure index. At seven of these airports there is a general increase in home value at greater distance from the airport.

These samples of data assembly and reduction from the AIF are revealing even though they represent only a demonstration of the types of research which can be undertaken with the file as a data source. We can see that on the basis of averaging,

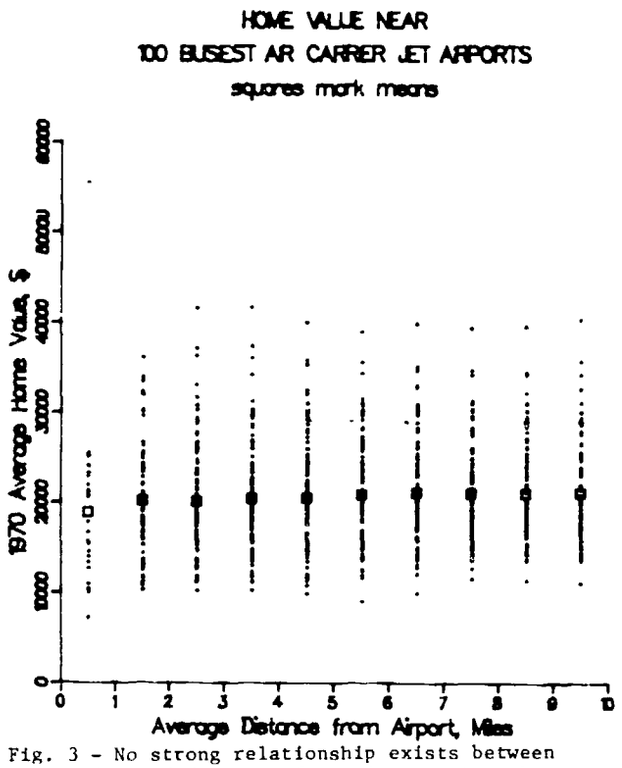


Fig. 3 - No strong relationship exists between home value and distance from airport when the values are averaged for all airports.

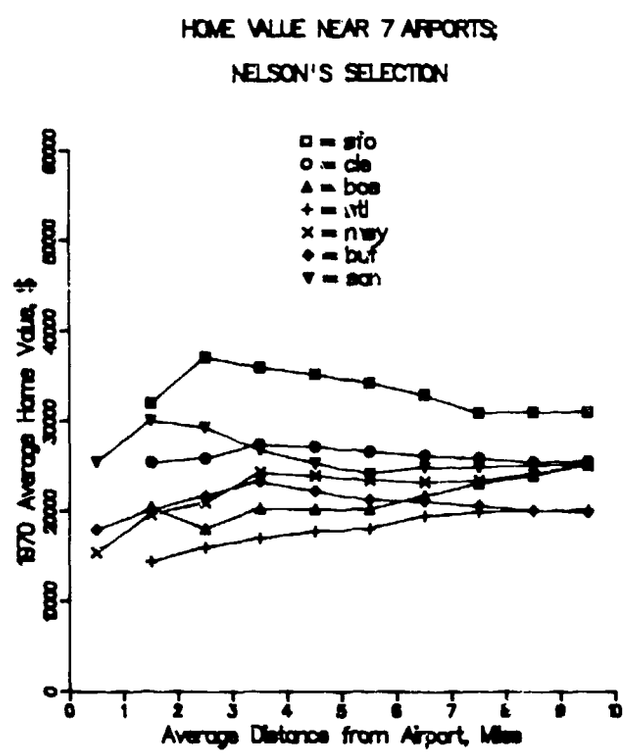


Fig. 4 - Example of value/distance relationship at individual airports.

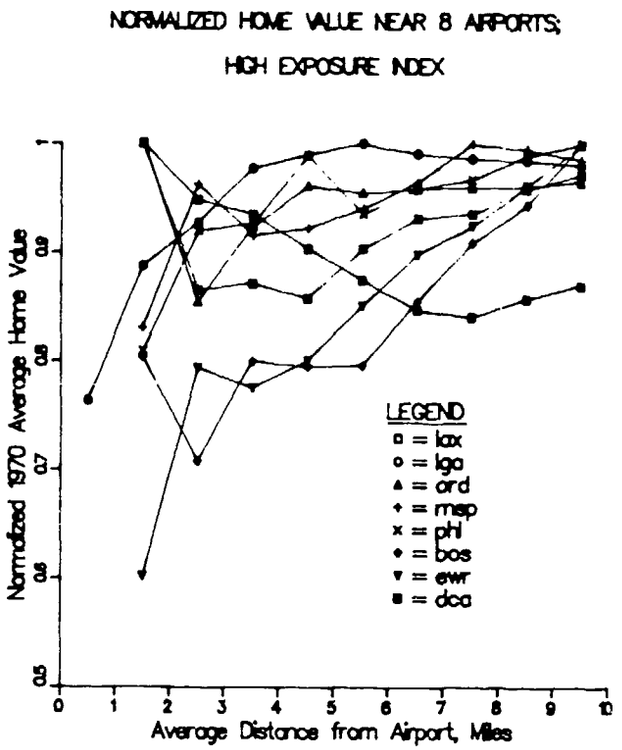


Fig. 5 - Example of relationship revealed better by normalizing the data.

location of airports does not show a strong influence on home value but that at individual airports, proximity probably does exert an influence, sometimes causing a rise in value, sometimes a decline. As a topic for further study, it would be appropriate to use the AIF to determine profiles of airports which influence property values upward and downward and to try to establish causal factors. It might be necessary before starting this type of investigation to merge other types of data into the file, a task which we normally welcome.

FUTURE DEVELOPMENT OF THE FILE

As new needs for airport information arise and new sources of data are discovered, the AIF should continue to improve in content as well as in ease and flexibility of use. At the end of the currently planned development period, there will be available a user's manual which includes full documentation regarding file structure, nomenclature, and suggested methods of use.

REFERENCE

1.J.P.Nelson,"Aircraft Noise and the Market for Residential Housing: Empirical Results for Seven Selected Airports," prepared for the Department of Transportation under Contract No. DOT-OS-70066,September 1978.

FAA AIRPORT EMISSIONS DATA BASE - DEVELOPMENT AND APPLICATION

C. William Patten

ORI, Inc.
Silver Spring, Maryland 20910

ABSTRACT

This paper describes the content and application of the FAA Airport Emissions Data Base. The data base and associated computer programs have been designed by ORI, Inc. for the FAA primarily for the purpose of analyzing the impact of alternative emission control measures on the airport area and the local air quality region. The pollutant emissions considered include oxides of nitrogen (NO_x), hydrocarbons (HC) and carbon monoxide (CO).

Currently the data base contains the necessary files for computing emissions from aircraft engines, auxiliary power units, aircraft ground service vehicles and refueling operations. Detailed statistical data have been included for the twenty-five most active commercial airports and thirteen general aviation airports. The data base includes actual data for FY 1975 and forecasts for fiscal years 1980, 1985, 1990 and 1995.

Computer programs have been written that compute NO_x, HC, and CO emissions from the data base files for current and future years and the particular scenario being analyzed. Examples of the data base files and the outputs from the Base Case scenario are presented.

THE PURPOSE OF THIS PAPER is to describe the development and application of the FAA automated Airport Emissions Data Base.

The data base and associated computer programs have been designed primarily for analyzing the impact of alternative aircraft related emission control measures on the airport area and the local Air Quality Control Region (AQCR). The pollutant emissions considered are nitrogen oxides (NO_x), hydrocarbons (HC) and carbon monoxide (CO).

OVERVIEW OF DATA BASE - Currently the data base contains the necessary files for computing the NO_x, HC, and CO emissions from aircraft engines, aircraft auxiliary power units (APUs), ground service vehicles (GSVs), and refueling operations over a takeoff and landing (LTO) cycle.

The data base at the present time provides the requisite data on the 25 most active air carrier airports in terms of annual aircraft operations and 13 general aviation airports including the 10 busiest airports. The data base includes actual aircraft operations data for FY 1975 and forecasts for fiscal years 1980, 1985, 1990 and 1995.

Input Files - The data base contains the following basic input files:

- Standard Data Input File
- Aircraft Operations File
- AQCR Emissions File
- County Emissions File
- Meteorological Data File.

Each of these files will be discussed briefly in this paper. A user's manual has been prepared which provides detailed information on the procedures for using and updating the data base and related computer programs (1).

Processing and Output - Two FORTRAN programs have been written to compute NO_x, HC, and CO emissions from the data files. FAA Pollution Program 1 (FAA P01) computes emissions (in kilograms) for up to 14 different types of base year (FY 1975) airport operations data (e.g., annual, quarterly, peak month, peak day) as well as operations broken down by operator category (e.g., air carrier, general aviation, air taxi, etc.), and by aircraft type (e.g., B707, DC10, and L1011, etc.). In addition, the number of gallons of gasoline and diesel fuel used by ground service vehicles and the amount of HC from evaporative losses and spillage are computed for each airport.

The FAA P01 program expands the standard input data and writes the data on an output file for use by FAA Pollution Program 2 (FAA P02) which computes the emissions for future years and the particular scenario being analyzed.

Detailed information on FAA P01 and FAA P02 is available in the FAA program documentation manuals (2).

STANDARD DATA INPUT FILE DESCRIPTION

The standard data input file consists of the following data sets:

- Aircraft Characteristics
- Landing-Takeoff Cycle Times
- Aircraft Engine Emissions
- Auxiliary Power Units
- Aircraft Ground Service Vehicles
- Airport Characteristics.

AIRCRAFT CHARACTERISTICS DATA SET - The aircraft characteristics data set is the crosswalk that provides pointers to the other data sets and for selecting the correct factors for computing the total pollutant emissions attributable to aircraft operations at a particular airport. Included in the data set are the aircraft name, its classification (jumbo jet, long-range jet, etc.), the number of

engines, the engine designation, a representative engine for look up in engine emissions data file, APU class name for look up in APU emissions data file, LTO class name for look up in the LTO emissions data file, and the aircraft ground service vehicle class name for look up in GSV emissions data file. Table 1 provides an example of each of these aircraft characteristics.

Table 1 - Aircraft Characteristics Data Set

Description	Example
Aircraft type name	B747
Aircraft classification	Jumbo Jet
Number of engines	4
Engine designation	JT-9D7A
Representative engine class	JT-9D7A
APU class name	BTCP 660-4
LTO class name	Jumbo jet
GSV class name	B747

LANDING-TAKEOFF CYCLE TIMES DATA SET - The aircraft classifications are used by the computer program to look up the landing-takeoff (LTO) cycle times used in computing engine emissions. The LTO cycle is separated into five distinct modes: (1) taxi-idle out for departure, (2) takeoff, (3) climbout, (4) approach and landing, and (5) taxi-idle in for arrival. The time (in minutes) in each mode is listed for each of the 11 aircraft classifications listed in Table 2. An option to the computer program allows airport specific taxi-idle times to be used in lieu of average taxi-idle times provided in this data set.

Table 2 - Number of Aircraft Types by LTO Cycle Classification Included in the Aircraft Characteristics Data Set

LTO Cycle Classification	Number of Types	Examples
Jumbo Jet	18	B747, DC10-10
Long-Range Jet	19	DC8-62, B707
Medium-Range Jet (3)	8	B727-100, B7X7
Medium-Range Jet (2)	14	B737-200, B7N7
Air Carrier Turboprop	7	L188, CV440
Piston Transport	1	M404
Business Jet	11	LR25, S210
General Aviation Turboprop	8	DH6, BE99
General Aviation Piston	41	BE60, C401
Helicopter	8	S61, 206A
Military Aircraft	4	Mil Jet, Mil Turboprop
Total A/C Types	139	

The airport specific taxi times are contained in the airport characteristics data set discussed below.

AIRCRAFT ENGINE EMISSIONS DATA SET - This data set contains the estimated emissions per hour of NO_x, HC and CO for each segment of the LTO cycle for each of the representative engines listed in the aircraft characteristics data set.

The engine emission rate data in this data set was obtained primarily from the FAA Systems Research and Development Service plus the EPA reports Aircraft Emission Factors (3), Aircraft Technology Assessment, Status of the Gas Turbine Program (4), and Compilation of Air Pollutant Emission Factors, Part A, AP42 (5).

With this data and the time in mode from the LTO cycle times data set, the engine emissions from a specific aircraft at a specific airport are computed. For example, the emission rates from the aircraft engine emissions data set are multiplied by the LTO cycle times for each mode and then summed over all modes to provide the total engine emissions in kilograms per LTO cycle for each of the pollutants of interest. Multiplying this factor by the number of engines provides the total engine emissions per LTO cycle for a particular aircraft at a specified airport. The number of LTO's is obtained from the aircraft operations file discussed below. The number of operations at an airport divided by 2 yields the number of LTO's for that airport.

AUXILIARY POWER UNIT DATA SET - The auxiliary power unit (APU) data set provides the data for computing APU emissions of NO_x, HC and CO. The data set includes:

- Representative duty times (in minutes)- defined as the time per LTO
- Emission rates for APUs (in kilograms per hour) for NO_x, HC and CO.

Representative duty times and emission rates for NO_x, HC and CO were obtained from the EPA technical report Aircraft Emissions at Selected Airports 1972-1985 (6).

APU emissions are computed for each aircraft type utilizing an auxiliary power unit. APU emissions per aircraft type are summed over all aircraft types at an airport to yield total airport APU emissions per time period.

AIRCRAFT GROUND SERVICE VEHICLE DATA SET - The aircraft ground service vehicle (GSV) data set provides data for computing GSV air pollutant emissions. The types of ground service vehicles included in the data set are listed in Table 3. Other data included in the file are average service times by GSV type for each aircraft type, engine types (e.g., gasoline or diesel), fuel consumption rates, and controlled and uncontrolled emission factors for gasoline and diesel engines.

Table 3 - Aircraft Ground Service Vehicle Types

Tractor	Food Truck
Belt Loader	Fuel Truck
Cabin Service	Conditioner
Container Loader	Airstart
Lavatory Truck	Ground Power Unit
Water Truck	Transporter

Each aircraft type in the aircraft characteristics data set receiving service from any ground service vehicle type has a GSV classification name, e.g., B747 which is used by the computer program to look up the GSV emissions data. GSV operating times are computed by multiplying one-half the total number of operations of each aircraft type by the service time of each vehicle type. The operating times are increased by specific factors to account for the time in the idle mode when vehicles are not serving aircraft. The operating times are combined with the fuel consumption rates and emission factors to compute ground service vehicle emissions at each airport by aircraft type. The computer program also

computes and prints out the gallons of automotive gasoline and diesel fuel consumed. The gasoline data is used in computing hydrocarbon emissions from evaporation during refueling operations.

The data in the GSV data set is based on the EPA report, An Air Pollution Impact Methodology for Airports (7). This report provided the average times in which each GSV services each of the ten specific aircraft types, GSV fuel consumption rates, and emission factors.

Commercial aircraft which utilize GSVs but which were not included in the EPA report, are assumed to have service times equal to aircraft types of similar size and seating capacity which are included in the report. For example, the EPA report does not provide GSV service times for the L1011 aircraft but does include service times for a similar aircraft, the B747. Therefore the L1011 is assumed to have the same service times as those listed for the B747.

AIRPORT CHARACTERISTICS DATA SET - This data set provides information on each airport and operates as a crosswalk to many other data sets and files. The following data elements are provided in this data set:

- LOCID - A three letter airport identifier
- Airport name
- Associated city
- County
- State
- AQCR
- EPA Region
- UTMG Coordinates
- Area in square kilometers
- Nearest city
- PANCAP-Practical Annual Capacity for FY 1975 and forecasts for 1980-1995
- Taxi-idle times by class of aircraft.

The capacity data for each airport is from the FAA Report on Airport Capacity Large Hub Airports in the United States (8). Airport specific taxi-idle times are from the FAA document, Airline Delay Trends 1974-1975 (9) and the FAA Office of Systems Engineering Management.

AIRCRAFT OPERATIONS FILE

The aircraft operations file contains the number of aircraft operations (arrivals and departures) for each of the airports in the data base. Operations are broken down into four operator categories (air carrier, air taxi, general aviation and military) and by aircraft type within each category. Operations data for the base year (FY 1975) include annual, seasonal (quarterly), peak month, peak day and hourly operations on the peak day. Annual forecasts of operations only are included for fiscal years 1980, 1985, 1990 and 1995.

The aircraft operations file is used in computing aircraft engine emissions, ground service vehicle and APU emissions. Operations are converted to Landing-Takeoff (LTO) cycles by dividing the number of operations by two.

SOURCES OF BASE YEAR DATA - The FAA publication, FAA Air Traffic Activity, Fiscal Year 1975 (10), provides a categorical breakdown of aircraft operations for the base year (FY 1975) by air carrier, air taxi, general aviation and military aircraft operations. Statistics on daily and monthly aircraft operations were obtained from FAA data files.

Air Carrier Aircraft Operations - Air carrier operations by aircraft type are determined by summing the aircraft operations of Certificated Route Air Carriers, Foreign-Flag Air Carriers, Intra-State Air Carriers, and Supplemental Air Carriers.

Air Taxi Operations - The number of operations by aircraft type for scheduled Air Taxi operators is obtained from the Official Airline Guide, North American Edition. The statistics on non-scheduled air taxi operations are obtained from the Airport Activity Statistics (A/S) file in the FAA Inquire Data Base.

General Aviation Aircraft Operations - No specific count is made by FAA tower operators pertaining to general aviation operations except whether the traffic is itinerant or local.

Local operations by aircraft categories (e.g., single engine piston, etc.) are estimated from a county breakout of active general aviation aircraft.

General aviation itinerant operations by aircraft types for each of the selected commercial and general aviation airports are based on an FAA sponsored survey.

Within each category of general aviation aircraft, the representative aircraft types are determined by using the national distribution of aircraft contained in The Census of U.S. Aircraft (11). The representative aircraft selected by aircraft category are shown in Table 4.

Table 4 - General Aviation Disaggregation Factors

Single Engine Piston		Turbojets	
C150	40%	Falcon	41%
PA28	13%	LJ35	38%
C172	13%	C500	31%
C177	9%	**Helicopters**	
C182	19%	47G2	50%
C210	6%	206B1	50%
Multi Engine Piston		**Turboprops**	
PA30	9%	BE65-90	56%
PASE	6%	MU2B	44%
C337	7%		
BE50	3%		
C310	56%		
C401	14%		
BE65	5%		

The representative aircraft were selected in the following manner. A list of aircraft was compiled comprising 90 percent of the national general aviation inventory by category (e.g., single engine piston and multi-engine piston, etc.). These aircraft were then aggregated by horsepower (or thrust). A representative aircraft was then selected for each horsepower (or thrust) group within each aircraft category. For example, referring to Table 4, the C150 was selected as representative of 40 percent of all single engine aircraft in the inventory.

Military Aircraft Operations - The FAA Air Traffic Activity, Fiscal Year 1975 (10) provides monthly counts and total arrival operations by military aircraft at each of the selected airports. The

breakdown of military aircraft by category (jet, turboprop, piston and rotorcraft is based on the national distribution for military aircraft for itinerant operations and the mix of based aircraft for local operations. Based aircraft information is contained in FAA report, Report on Airport Capacity Large Hub Airports in the United States (8). For those airports which reported local military aircraft operations but did not have military based aircraft, the national distribution figures are used.

AIRCRAFT OPERATIONS FORECASTS - Data on future aircraft operations by airport is furnished by the FAA Office of Aviation Policy. This data provides the annual operations forecasted at five year intervals through 1995 at each of the airports.

Forecasts of aircraft types are obtained from the UG3RD Baseline and Implementation Scenario (12).

EVAPORATIVE HYDROCARBON EMISSIONS

The FAA Airport Emissions Data Base currently includes programs for estimating the hydrocarbon emissions from refueling operations (displacement losses and spillage). Other sources of hydrocarbon emissions, such as fuel storage tanks and refueling tank trucks may be included in the expansion of the data base at a future date.

BASE YEAR (FY 1975) ESTIMATES - The estimated gallons of aviation gasoline and jet fuel sold and/or dispensed in FY 1975 at each of the airports are included in the aircraft operations input file. The amount of automotive gasoline used to refuel automobiles and ground service vehicles at air carrier airports is estimated by computing the gasoline used in the operation of ground service vehicles. Estimates of the FY 1975 automotive gasoline pumped at the 13 general aviation airports included in the data base are based on reports from the airport operators.

Estimates of the amount of jet fuel sold/delivered in FY 1975 at each of the commercial airports are based on data published by the Air Transport Association of America (ATA) on turbine fuel consumption (13). The ATA fuel consumption data includes both fuel used in domestic operations and fuel uplifted in the United States for international operations of the U.S. and foreign air carriers. The domestic fuel was adjusted upward to account for jet fuel used by general aviation at the commercial airports.

Estimates of jet fuel and aviation gasoline sold/delivered in FY 1975 at the 13 general aviation airports are based on information provided in response to written and verbal requests to the airport managers for data on fuel storage and handling. Similarly the estimates of aviation gasoline sold/delivered at the commercial airports in FY 1975 are based on data supplied by the airport managers and/or fixed base operators.

FORECASTS FOR FUTURE YEARS - Forecasts of fuel sold/delivered for fiscal years 1980, 1985, 1990 and 1995 are developed for the 25 air carrier airports for the three types of fuel as described in the following paragraphs.

Jet Fuel - Estimates of jet fuel consumption for each of the forecast years at each airport for domestic operations are derived by computing the percent increase or decrease in operations of turbine powered aircraft from the base year and then applying that percent to the FY 1975 fuel consumed for domestic flights at that airport.

The ATA provides estimates of turbine fuel for international flights uplifted in the U.S. for the five years 1977-1981 (13). These forecasts show an average annual growth rate of 3.4 percent. Projections of fuel uplifted at the air carrier airports with international flights are based on the FY 1975 data and this annual growth rate. These estimates are then added to the estimates for domestic operations to obtain total jet fuel sold/delivered at each of the commercial airports.

Aviation Gasoline - The estimates of aviation gasoline pumped at an airport are based on the percent increase or decrease from FY 1975 in piston aircraft operations at each airport.

Automotive Gasoline - Forecasts of automotive gasoline are derived from the estimated gasoline consumed by the ground service vehicles in each of the forecast years at each air carrier airport.

EVAPORATIVE HYDROCARBON EMISSIONS FROM AIRCRAFT/VEHICLE REFUELING - Aircraft and motor vehicle refueling losses are estimated by the following equation (14):

$$L_L = 12.46 \frac{SPM}{T_R}$$

Where: L_L = Loading loss, lbs/10^3 gal of fuel loaded

S = Saturation factor - Use S = 1.45 for splash loading (Av gas and Mo gas); S = 0.6 for submerged loading (jet kerosene)

P = True vapor pressure of fuel loading psia

M = Molecular weight of gasoline vapors

T_R = Bulk temperature of liquid loaded, ^oR ($T_R = T_F + 459.67$)

Control measures for reducing loading emissions include the application of vapor recovery equipment. Control efficiencies are reported to range from 90 to 98 percent (14).

The computer programs include an option to indicate if the refueling operations are controlled or not. Emissions from controlled loading operations are calculated by multiplying the uncontrolled emission rate by the control efficiency term:

$$\frac{1 - \text{Efficiency}}{100}$$

EVAPORATIVE HYDROCARBON EMISSIONS FROM SPILLAGE - Spillage losses from refueling aircraft are assumed to be negligible because significant quantities of spilled fuel are generally washed away promptly by ground crews due to fire hazards. Therefore spillage is estimated for automotive gasoline only, using the EPA estimate of 0.7 pounds of hydrocarbons per thousand gallons of throughput (14).

AIR QUALITY CONTROL REGION AND COUNTY EMISSIONS DATA FILES

The Air Quality Control Region (AQCR) and county emissions data files contain total CO, HC and NO_x emissions in metric tons for the base year (FY 1975) and the forecast years 1980-1995. The purpose of these files is to provide a reference to determine the contribution of aircraft engine emissions to the air pollution in a specified area. The data are used to determine the relative (percentage) amount each airport contributes to its respective county and AQCR. The primary source of data for the ACQR and county emission data files is the National Emissions Data System (NEDS) maintained by the EPA Office of Air Quality Planning and Systems.

Estimates of future emissions inventories are developed by applying factors developed by the Department of Energy (DOE) to the FY 1975 NEDS data. The DOE estimates the emissions implications of various fuel use projections.

METEOROLOGICAL DATA FILE

A meteorological data file has been included in the FAA Airport Emissions Data Base to provide a basis for dispersion modeling which will hopefully be carried out at some future time. The following meteorological parameters are included in the data base for each airport:

- Mean seasonal wind direction
- Mean seasonal wind speed
- Mean seasonal mixing height
- Mean seasonal stability
- Annual average station pressure
- Seasonal joint frequency distribution for wind direction, wind speed, and stability.

Local Climatology Data (LDC) is obtained from the National Oceanic and Atmospheric Administration (NOAA) in Silver Spring, Md. Stability array (STAR) data is obtained from the National Climatic Center (NCC) in Asheville, N.C.

This completes the discussion of the development of the FAA Airport Emissions Data Base. The remainder of this paper is focused on the analysis of a Base Case Scenario.

ANALYSIS OF A BASE CASE SCENARIO

The Base Case examines the contribution of aircraft related emissions of NO_x, HC and CO assuming aircraft emission controls are not implemented. Three new aircraft types are introduced during the forecast period: A300B, E7X7, and B7N7. The A300B represents all new twin engine wide-body aircraft. The B7X7 represents all new three engine medium range transports and the B7N7 represents all new two engine medium range transports. All piston and turboprop aircraft are phased out of air carrier operations by FY 1985.

FORECAST AIRCRAFT OPERATIONS, FY 1975-1995 - During the 20-year period FY 1975-95, total aircraft operations at seven major airports examined in the Base Case are forecast by the FAA to increase by about 38 percent while air carrier operations are expected to increase by about 25 percent as shown in Table 5.

CHANGES IN AIRCRAFT RELATED EMISSIONS FY 1975-1995 - The combined impact of the changes in air carrier fleet mix and the growth in operations is shown in Table 6. This Table shows the changes in aircraft related emissions in absolute and relative terms over the 20-year period. As can be seen from the table, emissions of NO_x and CO are forecast to increase while HC is expected to decrease except at Washington National and Greater Pittsburgh Airports. The decrease in HC emissions results from the introduction of new aircraft types and the replacement of older aircraft. The increase in HC at Pittsburgh can be attributed to the over 100 percent increase in aircraft operations shown in Table 5. At Washington National a decrease in HC emissions from air carrier operations is offset by increases in HC contributed by other activities. Overall, NO_x and CO emissions at the seven major U.S. airports could increase by about 95 and 50 percent respectively between fiscal years 1975 and 1995, if aircraft engine emissions standards are not imposed. Aircraft related HC emissions are forecasted to decrease at the majority of airports.

Other findings from the analysis of the Base Case include:

- Of the airport emissions sources analyzed (aircraft engines, APUs, GSVs, refueling operations), aircraft engines accounted for almost 90 percent of the NO_x and roughly 80 percent of the HC and CO in FY 1975. By 1995, if emission controls are not applied and the mix of gasoline engine GSVs remains unchanged from FY 1975, GSVs will contribute 9 percent of the NO_x, 15 percent of the HC and 19 percent of the CO.
- The majority (80 percent) of the 25 airports included in this study contributed less than 3 percent of the county and less than 1 percent of the AQCR emissions in FY 1975. However, by FY 1995, the percent contribution of aircraft related NO_x and CO emissions can be expected to increase. The percentage contribution to total AQCR CO emissions by the seven airports is expected to climb from 0.5 percent to 1.6 percent or 247 percent. The increase will result primarily from the forecast increase in aircraft related CO emissions and the forecast decrease in overall AQCR emissions due to stricter automobile standards (see Tables 7 and 8).
- In FY 1975, the aircraft related emissions at 12 of the 13 general aviation airports in the Data Base constituted less than 1 percent of the county and AQCR inventories of NO_x, HC and CO. The one exception is Fairbanks International. The aircraft related HC and CO emissions at this airport were over 4 and 5 percent of the county emissions respectively in FY 1975 due to the remoteness of the area.

Table 5 - Estimated Total Aircraft Operations at Seven Major Commercial Airports and Percent Change FY 1975 - 1995

Airport	Total 1975	Total 1995	Total % Increase	Air Carrier 1975	Air Carrier 1995	Air Carrier % Change
ATL	480,542	698,000	45	417,365	602,000	44
DCA	309,793	360,000	16	203,039	198,000	- 2
DEN	395,928	505,000	27	203,496	317,000	56
JFK	341,354	505,250	48	285,425	405,250	42
LAX	462,238	692,500	50	344,945	368,000	7
ORD	690,419	740,000	7	577,283	610,000	6
PIT	290,789	600,550	107	181,648	271,000	49
TOTAL	2,971,063	4,101,300	38	2,213,201	2,771,250	25

Table 6 - Estimated Absolute (Metric Tons) and Percent Change in Total Aircraft Related Emissions at Seven Commercial Airports FY 1975 - 1995

Airport	NO_x Amt	NO_x %	HC Amt	HC %	CO Amt	CO %
ATL	2878	108	-685	-19	1455	17
DCA	498	49	10	2	842	33
DEN	1449	120	-132	-10	1185	31
JFK	3377	126	-1394	-14	7717	58
LAX	1786	61	-2073	-36	1359	15
ORD	2624	63	-2889	-33	3345	24
PIT	1138	129	217	25	1804	87

Table 7 - Base Case Aircraft Related Emissions as Percent of County Emissions FY 1975 and FY 1995

Airport	NO_x 1975	NO_x 1995	HC 1975	HC 1995	CO 1975	CO 1995
ATL	9.6	14.9	5.2	3.7	4.0	11.5
DCA	11.5	14.4	3.9	3.9	3.0	12.8
DEN	3.6	5.5	2.2	2.0	1.4	3.9
JFK	2.2	4.4	7.8	6.6	2.9	16.1
LAX	0.8	0.9	0.7	0.4	0.4	1.4
ORD	1.5	2.1	1.6	0.9	1.2	3.0
PIT	0.7	1.2	0.7	1.0	0.4	2.2

Table 8 - Base Case Aircraft Related Emissions as Percent of AQCR Emissions FY 1975 and FY 1995

Airport	NO_x 1975	NO_x 1995	HC 1975	HC 1995	CO 1975	CO 1995
ATL	2.3	3.5	2.1	1.5	1.4	4.0
DCA	0.6	0.8	0.2	0.2	0.2	1.0
DEN	1.2	1.8	0.9	0.8	0.5	1.5
JFK	0.3	0.6	0.7	0.6	0.3	1.6
LAX	0.5	0.6	0.5	0.3	0.2	0.8
ORD	0.6	0.7	1.0	0.5	0.5	1.3
PIT	0.2	0.4	0.4	0.5	0.2	1.2

FAA-EPA TAXI TIME ANALYSIS - The purpose of this analysis is to determine the impact of considering EPA defined taxi times as opposed to actual average (FAA) taxi times on air pollutant emissions in the airport vicinity and local EPA Air Quality Control Region (AQCR). The basic difference between EPA and FAA taxi times is that EPA taxi times do not vary by airport, whereas, FAA taxi times are airport specific. Since the amount of time an aircraft spends in the taxi-idle mode of operation is a variable primarily dependent on the particular airport under study, the FAA airport specific taxi times are probably more realistic than the EPA times.

Table 9 presents a comparison of aircraft related NO_x, HC and CO emissions computed using FAA and EPA taxi times for the eight airports considered in this analysis. Substantial increases in HC and CO emissions occur when EPA taxi times are used in emission calculations at airports reporting lower actual average taxi times. The greatest impact is in HC emissions. For example, aircraft related HC emissions at Washington National Airport increased 74 percent when EPA taxi times were substituted for FAA taxi times in engine emission calculations. J.F. Kennedy is the only airport of the 38 airports in the data base where actual average taxi times exceed EPA taxi times which accounts for the decrease in emissions shown in Table 9 for JFK.

The following findings may be drawn from the analysis:

- The time spent by aircraft in the taxi idle mode of operation has a significant impact on HC and CO engine emissions and a relatively small impact on emissions of NO_x.
- The use of EPA taxi times as opposed to FAA taxi times in aircraft engine emission calculations probably over estimates HC and CO emissions at practically all airports in the United States.

SUMMARY

This paper has attempted to provide an overview of the development and use of the FAA Airport Emissions Data Base by describing the files which make up the Data Base and by highlighting some of the results obtained under a Base Case scenario. The analysis of the Base Case seems to indicate that the FAA Data Base and related computer programs are fully adequate to provide a framework for the analysis of proposed aircraft engine emission standards on the airport air quality control regions. As mentioned at the beginning of the paper, this is the intended purpose of the FAA Airport Emissions Data Base.

Table 9 - Aircraft Related Emissions Base Case Scenario FY 1975

Airport	NO_x FAA Taxi Times	NO_x EPA Taxi Times	NO_x Δ%	HC FAA Taxi Times	HC EPA Taxi Times	HC Δ%	CO FAA Taxi Times	CO EPA Taxi Times	CO Δ%
ATL	2657	2803	5	3518	4852	38	8531	10516	23
DCA	1023	1127	10	635	1103	74	2515	3603	43
DEN	1207	1312	9	1323	2311	75	3797	5253	38
JFK	2678	2618	-2	9846	8879	-10	13378	12087	-10
LAX	2919	3062	5	5828	8286	42	9220	12114	31
ORD	4138	4223	2	8674	9841	13	14009	15441	10
PIT	883	987	12	863	1964	128	2061	3697	79
OPF	11	12	9	97	118	22	2464	2795	13

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance provided by numerous persons during the preparation of the Data Base and the analysis. Aircraft operations forecast data was provided by Gene Mercer and Bernard Hannan, FAA/Office of Aviation Policy - AVP-120. Most of the aircraft engine emissions rate data on current engines was provided by William Westfield, FAA/Systems Research and Development Service - ARD 550. Richard Munt and William Houtman of the Environmental Protection Agency, Division of Emission Control Technology, Ann Arbor, MI, provided helpful suggestions on computing emissions rates for engines not yet in production. Bruce Jordon, Charles Mann and Harold Barkahu of the EPA Office of Air Quality Planning and Standards, Durham, N.C., provided the regional air pollution emissions data from the EPA National Environmental Data System. Mr. James T. Alexander, Jr., Northern Virginia Regional Office of the State Air Pollution Control Board, Commonwealth of Virginia, provided helpful information on air pollution emissions in Arlington County, Virginia. Growth factors used to estimate the county and air quality control region data for future years were provided by Edward Pecham, Department of Energy. Actual taxi-idle times used in the analysis were provided by Seymour Horwitz, FAA/Office of Systems Engineering - AEM 100.

The airport meteorological data was developed by Robert C. Koch, GEOMET Incorporated, under a subcontract to ORI. Also acknowledgement is made of the assistance provided by airport and fixed base operator personnel in providing data on fuel used at the airports considered in the analysis.

This work has been prepared by ORI, Inc. under the supervision of the FAA Technical Officer, Nicholas P. Krull, AEE-10, whose guidance and helpful suggestions are also gratefully acknowledged. Finally, the author wishes to acknowledge the many contributions to this work by his coworkers at ORI who actually developed the Data Base and computer programs and who did most of the analysis: Elisabeth Battino, James Bauchspies, Lawrence Kaplan, Paul King, Regina Kupersmith, Madeliene Robinson, William Simpson, and Fred Zusman.

REFERENCES

1. "FAA Airport Emissions Data Base Users' Manual," FAA-EQ-78-06, Federal Aviation Administration, April 1978.

2. "FAA Airport Emissions Data Base," Program Documentation Manuals Pollution Program 1, Report No. FAA-EQ-78-07 and Pollution Program 2, Report No. FAA-EQ-78-08, Federal Aviation Administration, March 1978.

3. Robert G. Pace, "Aircraft Emission Factors," EPA Technical Support Report, March 1977.

4. Richard Munt and Eugene Danielson, "Aircraft Technology Assessment, Status of the Gas Turbine Program," December 1976.

5. "Compilation of Air Pollutant Emission Factors, Part A," AP 42, Environmental Protection Agency.

6. "Aircraft Emissions at Selected Airports 1972-1985," Environmental Protection Agency, January 1977.

7. "An Air Pollution Impact Methodology for Airports-Phase I," APTD-1470, Environmental Protection Agency.

8. "Report on Airport Capacity, Large Hub Airports in the United States," FAA-AVP-77-26, Federal Aviation Administration, May 1977.

9 "Airline Delay Trends 1974-1975," FAA-EM-77-2, Federal Aviation Administration, 1977.

10. "FAA Air Traffic Activity, Fiscal Year 1975," Federal Aviation Administration.

11. "Census of U.S. Aircraft as of December 31, 1975," Federal Aviation Administration.

12. "UG3RD Baseline and Implementation Scenario," Federal Aviation Administration.

13. "United States Airline Industry Turbine Fuel Forecast," Air Transport Association of America, May 1977.

14. "Supplement No. 7 for Compilation of Air Pollutant Factors," 2d Edition, Environmental Protection Agency, April 1977.

DISCUSSION

GELINAS: What kinds of emission factors did you use for ground service vehicles and what time factors? I know Argonne has developed data on operating times for various types of ground service vehicles on the airfield. That is the first question.

The second question deals with the APU emissions. I would like to know how you estimated the APU emissions.

PATTEN: In both cases, the data we have come from EPA-published data. The EPA data for the ground service vehicle times and emissions per gallon of fuel burned or gallon of diesel fuel burned were published in EPA reports. The source of those reports is Argonne.

I am now looking for additional data on ground service vehicles. Every place that we looked it came back to Argonne.

GELINAS: I know I had a lot of problems in the study. We also looked at ground service vehicle emissions and aircraft emissions, and were trying to find sources on the airfield to reduce, and I had a hard time finding data on ground service operation times.

PATTEN: One additional thing, we asked Greiner Engineering in Tampa, Florida what they had, and they came back with the same EPA data except they had accumulated data for general aviation aircraft. We have some ground service vehicles in the business, so we did add that. Other than that, it is straight out of EPA-published data.

GELINAS: On the APU operations, did you assume certain times of operations of the APU; for instance, the APU would be operating while they were landing and taxiing, idling, and also while they were parking, and did you go through a process of assuming that while the aircraft was at the gate, for one hour the APU was operating, and after that, it shut down? Did you go through such a process?

PATTEN: We did not compute those times. We found them in published data where you have APU's by type of aircraft, and the operating time of that APU per landing and takeoff cycle. The data gave us operating time and emissions per minute of operations.

GELINAS: I did want to comment on the ground service vehicle emission factors. They are really in poor shape in terms of accounting for deterioration and age of the vehicles. The ground service vehicles are not maintained very well. I think there is a need for improvement, although I'm sure they don't amount to very much as a total percent of emissions on the airfield.

YAMARTINO: You mentioned 90 percent of the NO_x and 80 percent of the CO and hydrocarbons for this base year came from the aircraft engines. What else was being counted there? Does that include cars and ground service vehicles?

PATTEN: It counts the four aircraft-related elements that I showed at first, the aircraft engines, the APU's, the ground service vehicles, and evaporative hydrocarbon losses from refueling only; 80 percent of that total.

YAMARTINO: It does include ground service vehicles?

PATTEN: Ground service vehicles that service aircraft, not the taxis or any of the other traffic.

DALEY: What are the plans for updating the data base? Will they be updated annually, or is there any specific plan?

PATTEN: I can only speak for this data base, not for Dave's, but we are in the process of updating the forecast, in terms of annual operations, quarterly operations, all the way down to peak hour, and also to update the fleet mix.

WINER: Since you asked, we don't have any specific plan to update. There are so many parts of ours that we will update some parts regularly and other parts irregularly. We would try to update the operations information at least annually, probably more often, but some of the others are pretty static.

VALIDATION STUDIES OF AIR QUALITY MODELS AT DULLES AIRPORT

by

D.G. Smith, E.A. Taylor, S.M. Doucette, B.A. Egan

Environmental Research & Technology, Inc.
3 Militia Drive, Lexington, MA 02173

ABSTRACT

Initial results of a recently completed monitoring and analysis program designed to assess the impact of emissions from the Concorde SST have led to further review of the Basic assumptions made in a number of airport air quality models. Although fundamental details of the dispersion process are often ignored, these assumptions are often adequate for a particular scale of analysis. This scale implies a basic limit of resolution for each model. Many models use simulation techniques that generally overestimate concentrations associated with aircraft emissions, particularly in the near field. This paper discusses the limitations of these techniques and presents illustrative cases for which more refined modeling analysis is required. Preliminary results of comparisons between predicted CO concentrations and those measured during the Concorde monitoring program show that initial plume rise and jet wake dispersion of effluents, as well as choices of atmospheric dispersion coefficients, have important effects upon pollutant concentration estimates for receptors located within a kilometer of the source pathway.

1. INTRODUCTION

Since the passage of the National Environmental Policy Act (NEPA) and the Clean Air Act (CAA) of 1970, air quality models have been used quite frequently to assess the potential impacts of new airports or, more frequently, the changes in design or operation of existing airports.

Many air quality studies of airports and their associated impacts have demonstrated the dominant role of nonaircraft sources in determining air quality at the airport site boundary and beyond. Regulatory agencies, however, continue to be concerned about impact on air quality of public areas within airport boundaries, as well as on the immediate area. For rural and suburban airports, the concentration of several types of transportation sources in one small area may represent the largest single area source of carbon monoxide (CO) and nitrogen oxide (NO_x) pollutants in the region. For a rural air basin with limited meteorological dilution capacity, this area source could be a significant contributor, although probably not the dominant one, to regional photochemical oxidant levels. For all of these reasons, there is continuing federal regulatory interest in assessing the adequacy of both aircraft emission standards and state implementation plans (SIPs) for control of airport impacts on community air quality. In many cases, general-purpose Gaussian plume models describing pollutan transport have been combined with airport source inventory models that compute the geographic distribution of emissions. An early example is the well known Northern Research and Engineering Corp. model (NREC), which incorporated the Environmental Research & Technology air quality transport and dispersion model (ERTAQ) (see Platt et al. 1973).

Often the combination of models used for impact assessment has been a custom version adapted for a single study. The FAA and Argonne National Laboratories (Rote et al. 1973), on the other hand, have developed a combination inventory and transport and dispersion program, the Airport Vicinity Air Pollution model (AVAP), which includes special methods for computing the concentrations due to accelerating and decelerating line sources, in addition to a large inventory of more conventional point, area, and line sources. In both cases, the validation of the model is usually assumed to be that ascribed to the underlying Gaussian point, area, or line source models. Although it is true that when properly applied, simple Gaussian plume models are currently the best validated dispersion models, the addition of many other assumptions by means of subroutines can often interfere with the overall accuracy and precision of model predictions.

Many times, a small scale monitoring program has been undertaken to demonstrate the accuracy and precision of model predictions for the particular meteorological conditions measured. Several such programs have been performed to validate AVAP.* Often, however, complex source configurations or limitations in locating receptors and a limited range of weather conditions have limited these comparisons so severely that very little could be said about the accuracy of assumptions made in the modeling.

The lingering questions about the validity of airport modeling methods can generally be traced to one of the following.

1) There are many models applied to airports that, when used at the same location, give widely varying results.
2) The assumptions in the models used are not always clearly defined, and their applicability to specialized geometries of sources at airports is often questionable.
3) The validation experiments for the

models designated as airport models are few, and those that exist have not been particularly successful, even for relatively sophisticated models.

4) The scales of interest to the user may not coincide with those for which the mathematical model was developed - a user often expects finer resolution of concentration profiles or better agreement between a few short-term measurements and predicted average concentrations that are reasonable.

5) Analysis of a "hot spot" problem is attempted with a model that does not contain the right physical model to adequately simulate or describe it.

Many of these problems result from misunderstanding of modeling capabilities or intents, often due to problems of user interpretation as it is with model design or documentation.

The key concept here, model validation, requires further definition at this point to interpret the value of the present experimental results. The process of model validation for a dispersion model is a gradual one because of the number of parameter assumptions simultaneously evaluated. It is expected that a large ensemble of experimental results will show that a given model is generally successful in describing the concentration field produced by a particular source configuration under each identified combination of meteorological transport and diffusion conditions.

At least four concerns must be addressed when model validation is attempted: (1) is the type of model selected appropriate for the time and distance scales of the phenomenon, (2) are the comparative field measurements representative of these same scales in terms of sampling and averaging times, (3) is the possibility of limiting the number of unmodeled variables sufficiently that the model parameters can be tested, and (4) are the number of experiments large enough to determine the desired number of model parameter values with a reasonable degree of precision. The current status of airport air quality modeling, discussed later, reflects all of these problems. While the latter two types may be of greatest concern to the scientist or engineer evaluating models, the first two are often most troubling in the regulatory assessment process.

A description of the experimental measurements obtained at Dulles Airport in 1976 and 1977 is given in Section 3. Initial efforts at determining plume rise and dispersion rates used the CO data from four levels on a single 52-foot tower and ground-level CO sensors at two successive downwind distances. More recent analyses have used data collected at five levels on 80-foot towers at each of the three distances from the taxiway. Preliminary results of attempts to fit these new data with existing models and their variants formulated from the 52-foot tower data are discussed in Section 4.

Section 4 and the conclusions in Section 5 discuss the requirements for improved modeling of near-field dispersion rates and plume rise, as well as suggestions for use of the recently acquired Dulles data for "validation" of model refinements. The discussion of the measurement results obtained at Dulles shows that models need not reproduce all the dynamic and kinematic details of the dispersion process to be successful at larger distances, but that adequate understanding of the observed rates of dispersion and assessment of near-field "hot spot" impacts both require more exact descriptions for accurate modeling of the dispersion process. Although the majority of the Dulles experiments were devoted to CO measurements associated with taxiing aircraft, potential model refinements are sure to have an impact on the question of nitric oxide/ nitrogen dioxide (NO/NO_2) conversion and dispersion rates during takeoff operations.

2. STATUS OF AIRPORT AIR QUALITY MODELING

An airport air quality model has to perform two major functions. First, it has to calculate a geographical distribution or inventory of source emission rates; second, it has to simulate transport and dispersion of those emissions to predict pollutant concentrations at designated receptors of interest. The airport model can be structured to have nearly independent inventory and transport submodels. For a majority of the current models, this is the case - or at least an option. For this reason, the models whose features are denoted in Table 1 are emission inventory models. Those listed in Table 2 are transport and dispersion models developed to describe short-term (less than 24 hour) concentration patterns.

TABLE 1

AIRPORT EMISSIONS MODELS

Name	Classes of Aircraft	Special Aircraft Operation Features
SRIC*	12, from AP-42	Basic LTO cycle Constant emissions User designated runway use
SRIC IEIAQ**	12, from AP-42	Basic LTO cycle Service vehicles and ground-based APU's
AIRPTM	6, from AP-42	LTO cycle as in GEOMET Temporal distribution of traffic Mode times depend on runway use
AVAP***	10, assigned one of seven engine types and one of four operation classes	Basic LTO cycle Service vehicles and APUs Finite exhaust "fan" Runway use associated with wind quadrant Temporal distribution of traffic
AQAM	37 military, 10 user defined	Expanded LTO cycle Two-phase approach and climbout Service vehicles and APUs Temporal distribution of traffic Runway use selected by 16 sectors of wind rose

*Platt et al. 1971
**Platt et al. 1973
***Record et al. 1975
****Rote et al. 1973
*****Rote and Wagen 1975

*Other papers at this conference will discuss recent efforts to "validate" the AQAM model of the U.S. Air Force (Rote and Wangen 1975).

[illegible]

Table 3 lists airport air quality models that combine the features of those in Tables 1 and 2, although this list is undoubtedly incomplete. In some cases, a transport and dispersion model (such as PAL or ERTAQ) is sufficiently flexible in its design to allow the same program to be used for many nonairport source applications, a quality that often confuses the identity of an "airport air quality model." More detailed discussion of the specialized features, assumptions, and limitations of most of the models listed is available from the reviews of Haber (1975) and Smith (1978) and from the corporate or agency developers identified in references or Table 3.

TABLE 3

COMPREHENSIVE AIRPORT AIR POLLUTION MODELS*

Model Name	Developer	Contracting Agency
AIREC or NREC	Northern Research Engineering Corporation	EPA
GEOMET	Geomet Incorporated	EPA
ERTAQ/STABILA	Environmental Research & Technology Northern Research Engineering Corporation	FAA
AVAP	Argonne National Laboratory	FAA
AQAM	Argonne National Laboratory	Air Force
BOEING	Boeing Computer Services	Proposal to FAA
LMSC	Lockheed Missile and Space Company	Proposal to FAA
Landrum/ Brown	Landrum and Brown	None

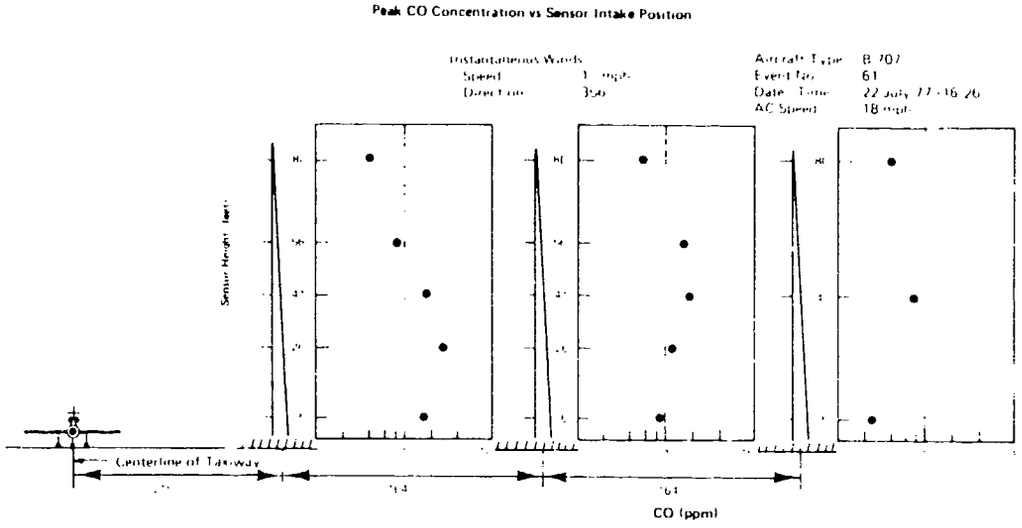
It is noted that Gaussian models have already been subjected to the most comprehensive validation efforts, are one of the best understood types of transport model, and adequately predict contrations for point sources between distances of 100 meters and 10,000 meters, but not all of the assumptions specific to aircraft sources have been validated. For pollutant concentration estimates in the near field (distances less than 100 meters) or for distances closer than five obstacle heights in situations where the wind flow near the source location must pass around obstacles or buildings, Gaussian models are not generally adequate. For greater distances, a Gaussian model with special assumptions about initial source geometry and amplified dispersion rates may be adequate. In the vicinity of a source, especially those adjacent to obstacles, only the numerical advection diffusion models (such as EGAMA in Table 2), wind tunnel simulations, or empirical turbulent wake models (e.g., Briggs 1976; Smith 1978) yield results that can readily be related to validation measurement experience. Typical examples of airport-related pollution problems that require these alternate analysis methods include: (1) aircraft engine starts beside terminal buildings, (2) taxi stands, (3) depressed access roadways near buildings, and (4) multiple parking garages. Whenever the geometry for one of these situations is more complex than those for which the proposed mathematical models have been validated, supplementary wind tunnel or field measurement studies are recommended.

Most of the modeling efforts subsequent to the NREC model rely on its basic framework, including the use of a Gaussian plume transport model. Many differ in their degree of detail in treating initial source geometry or in accounting for the variety of aircraft operations that constitute the time period modeled. The NREC model covers all basic operations occurring at an airport, with primary emphasis on developing a typical landing-takeoff (LTO) cycle for passenger aircraft.

Since the NREC model was first published, considerable developmental effort has gone into improving the calculation of the distribution of the pollutants among the sources defining the LTO cycle and the dispersion of the pollutants from the point and line sources to receptors. This development effort has resulted in the detailed airport/military air base models represented by the Airport Vicinity Analysis Program and Air Quality Airport Model (AVAP/AQAM) developed by the Argonne National Laboratory (Rote et al. 1973; Rote and Wangen 1975). For example, in the climbout portion of the LTO cycle, the NREC model has all aircraft (12 classes) follow the same departure path. This path is approximated in the dispersion algorithm as a series of point sources of varying strength; whereas in AQAM, 50 aircraft types are represented with each following a different departure path.

The AVAP model is the most sophisticated code yet developed for predicting the impact of all sources at commercial airports for averaging time intervals ranging from one hour to one day. Emissions are simulated by a combination of point, area, or line sources. Point sources include smoke stacks, vents, or small sources of evaporated materials. Area sources include complex mixtures of motor vehicles (cars, trucks, aircraft) operating in parking lots, aircraft ramp areas, etc. Line sources are divided into uniform and nonuniform, according to whether the vehicles moving along the line are moving with approximately constant speed or are accelerating (or decelerating). Uniform lines include access roadways and taxiways. Nonuniform lines include LTO operations on runways and approach and departure paths

Figure 1 Three-Tower Experiment Data



(treated as inclined lines).

3. DULLES EXPERIMENT MEASUREMENTS

3.1 Objectives

The measurement program at Dulles International Airport was initiated in response to an order by the Secretary of Transportation to monitor pollutant emissions and noise levels associated with Concorde aircraft operations. To meaningfully assess the influence on air quality, three types of pollutants were monitored: CO, NO_x, and hydrocarbons (HC). Measurements were obtained at nearby regional monitoring stations, but principal attention was devoted to arrays of sensors placed on the airport in the vicinity of aircraft operations. [The locations and periods of use for these arrays are detailed by Smith et al. (1977)].

Early measurements indicated low concentrations that would not be explicable with many conventional airport models, apparently because previous models developed specifically for airports have generally ignored plume rise. Although many model applications are not severely limited by this omission, when conservative estimates of airport impacts at distances of 2 to 10 miles are at issue, it is essential to consider both the direct and indirect (augmentation of σ_z) effects of plume rise for validating model predictions at closer distances. Some results of previous analyses (Smith et al. 1977) which show the importance of plume rise in explaining the concentration profile on an 80 foot tower at a distance of 215 feet from the taxiway, are illustrated later.

The initial dominance of the mechanical turbulence associated with jet exhaust wake cannot be ignored, but as mentioned above, does not appear to be adequately separated from the plume rise or effects of ambient turbulence on the basis of the Dulles experiments. Thus, the early results led to a design of a progressively more sophisticated experiment, using first one, then two, and finally three towers instrumented at three to five levels with CO sensor probes. Meteorological data included two levels of wind direction and speed and temperature and its gradient.

3.2 Measurement Methods

The Dulles three-tower array that provided the data analyzed for this paper is shown in Figure 1, along with three sample profiles of CO versus height for each tower distance. The CO values were derived from the measurements of one experimental "event." Wind speed and direction were measured at the 80 foot and 14 foot levels on the first tower; temperature gradient was measured between 67 feet and 14 feet on the same tower.

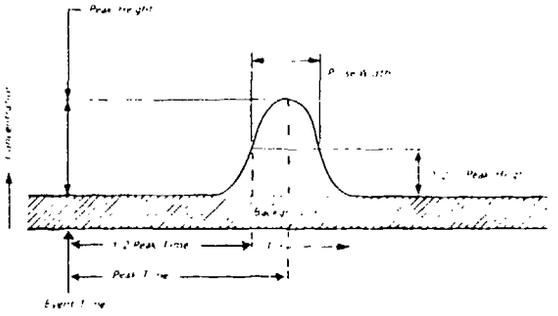
As indicated in Figure 1, CO was measured at 13 points by pumping air samples continuously through identical volume sampling lines into individual Ecolyzer units. These units were housed in an air conditioned shelter. They were periodically calibrated by sequential switching of the intakes to the same 18 ppm concentration.

The calibration system was designed to allow precise timing of sensor exposure to calibration gases of different concentrations so that response time constants and linearity of signal amplitude could be determined. Since an aircraft passage "event" was expected to produce a pulse representing concentration versus time (as shown in Figure 2), the measurement of sensor system time characteristics was deemed important. The time constant of the Ecolyzers averaged 12 seconds, and their threshold sensitivity averaged 0.25 ppm.

The concentrations shown in Figure 1 represent the instantaneous peak values from the relatively high speed chart records. Figure 2 is idealized in the sense that the skew (to the right) observed as a result of the time response, and potentially the pollutant distribution, is not shown. When the data was reduced, both the time-to-peak and the time-to-half-peak were

recorded in addition to the peak CO value, the full-width-at-half-maximum time, and the background CO - so that skewness could be accounted for in future modeling. The details of the

Figure 2 Pollution Parameter Definition



method used in the current event modeling to correct the peak concentrations for sensor response time are given in Smith et al. (1977).

In addition to concentration measurements, documentation for each event included event time, direction of aircraft travel, departure or arrival made, time to travel 50 m, and meteorological conditions. Wind direction and speed were averaged over three minutes. The value of σ_θ for the same averaging time was found from 30 six-second samples for each event, commencing at the recorded event time. The specific ranges of meteorological conditions are given with the results below. The taxiing activity pattern, the orientation, of the towers at Dulles, and simplicity for modeling were factors leading to this selection. It is also important to note that the current analysis has been limited to the two aircraft types with the largest populations in the three tower data set: Boeing 707s (37 events) and Boeing 727s (24 events). The previous two-tower experiments included 31 B707s, 34 B727s.

4. EVENT MODELING

Carbon monoxide concentrations associated with taxiing aircraft were calculated at each tower location following the method described in Smith (1978). Briefly, the equation used was the quasi-instantaneous line source model adjusted to include the influence of plume rise. That is:

$$\chi = \frac{Q}{2\pi(S + u_p)\,\sigma_z\sigma_x}\left[\exp -\frac{1}{2}\left(\frac{x - u_n t}{\sigma_x}\right)^2\right] \cdot \left[\exp -\frac{1}{2}\left(\frac{z - h}{\sigma_z}\right)^2 + \exp -\frac{1}{2}\left(\frac{z + h}{\sigma_z}\right)^2\right] \quad (1)$$

where

Q is the pollutant emission rate (gm/sec),

S is the aircraft taxi speed (m/s),

u_p is the wind speed component parallel to taxi path (m/s),

x is the distance downwind (m),

u_n is the wind speed component perpendicular to taxi path (m/s),

t is the travel time (secs),

σ_x is the plume width (m),

z is the height at which calculation is made,

h is the plume centerline height, and

σ_z is the vertical plume spread.

Plume rise was incorporated using the equation developed using the one tower data set described earlier (Smith et al. 1977). Of interest is the general applicability of this plume rise formula to other data sets. The equation for plume rise Δh developed by Yamartino (1977) from the single-tower data set is:

$$\Delta h = A + B/\sqrt{u} \quad (2)$$

TABLE 1

COMPARISON OF HEIGHT OF SENSOR OF MAXIMUM TO MEASUREMENT WITH PREDICTED PLUME CENTERLINE HEIGHT (feet)

Event No.	Predicted Plume Centerline	Height of Peak Monitored Concentration Tower 1	Tower 2	Tower 3
		B707 Aircraft		
		Stability A		
67	18	20	20	6
119	12	20	41	41
123	16	20	20	6
		Stability B		
22	19	50	50	41
		Stability D		
1	30	20	50	41
48	16	20	20	41
49	20	20	41	41
69	14	20	6	6
85	17	50	50	80
89	17	20	6	6
90	16	6	20	6
102	14	20	41	41
105	16	20	80	41
109	17	20	6	41
118	12	6	6	6
132	26	20	50	80
139	24	6	41	41
		B727 Aircraft		
		Stability A		
116	14	6	50	41
		Stability D		
25	20	80	50	80
31	24	20	50	80
101	15	20	6	6
127	13	6	6	6

where A and B are parameters that best fit the data when assigned the values -2.6 and 65, respectively, and u is the wind speed (mph) perpendicular to the taxi path. The plume centerline was assumed to have reached its final height at the first tower. Table 4 lists the predicted height of the plume centerline and the height of the peak concentration monitored at each tower.

An intial mixing volume consistent with the previous calculations (Smith et al. 1977) was assumed. Table 5 lists these dimensions for the B707 and B727 data sets. The atmospheric stability associated with each event was estimated by the gradient Richardson number using the temperature and wind velocity differences as recorded at the first tower. As noted above, most of the events occurred during neutral and unstable atmospheric conditions. Events with peak monitored CO concentrations below a threshold of 0.2 ppm were not considered.

TABLE 5

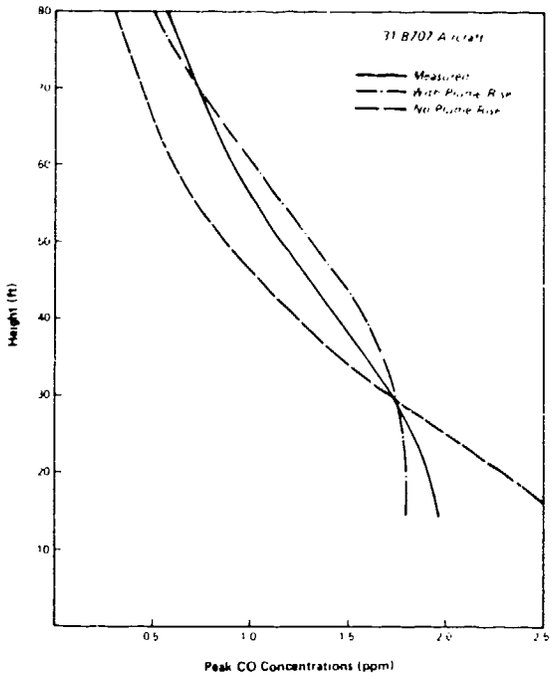
DIMENSIONS OF THE INITIAL MIXING VOLUME FOR BOEING 707 AND 727 AIRCRAFT

Aircraft Type	Height (m) (2.36 σ_z)	Distance Between Engines (m) (4.72 σ_y)
707	12.93	51.26
727	10.36	5.84

The previously reported (Smith et al. 1977) comparison of the vertical profile of the calculated CO concentrations and levels monitored during the two-tower experiment (February and March 1977) for B707 events is presented here for comparison with similar current calculations for the three-tower data set. Figure 3 illustrates the importance of plume rise. Plotted in the figure is the average predicted and monitored concentrations vs. height at the first tower (215 feet from the centerline of the taxiway).

The analysis of 34 B727 events, as well as nine Concorde events, demonstrated similar results. Because the emission rates from a B727 are much lower than from the B707, predicted and measured concentrations are both lower. In fact, beyond the first tower, the measured B727 concentrations often fell below the threshold level for adequate measurement precision (0.25 ppm). The average measured concentration for the most distant 14-foot sensor was actually higher than that for the middle distance 14-foot sensor. It is not clear whether this effect is a byproduct of the lack of continued plume rise for the B727s or whether it is merely a product of measurement uncertainty at the low levels observed. For both B727s and Concordes, the observed profile of peak concentrations is roughly constant with height -- suggesting that either several distinctly different plume heights may be included in the data set, or actual plume spread in the vertical may be more than the spread that has been predicted here. The height of the centerline was generally calculated to be less than the height of the sensor that monitored the peak. Also it should be

Figure 3 Effect of Plume Rise on Model Comparison with Observations



noted that the average monitored centerline height during neutral atmospheric conditions increased from 24 to 36 feet from the first to the third tower for the B707 and from 54 to 43 for the B727 events. This implies that the plume does not in fact level off after reaching the first tower.

Table 6 lists the monitored peak CO levels and the maximum predicted instantaneous concentrations at each of the three towers for the events selected. The events are grouped by the prevailing atmospheric stability and aircraft type. As was found previously, the monitored levels associated with taxiing B727 aircraft rarely led to monitored CO concentrations greater than the 0.2 ppm threshold.

Predicted pollutant levels were overpredictions compared to the monitored values for all events at the first tower and all but one (Event #105) at the second and third towers. This overprediction of pollutant concentrations has been the usual result of such Gaussian model comparisons to date. It is suggested that the overprediction here is due to the assumption of an initial mixing volume that is much too small.

The most recent analysis, which involves fitting of a similar Gaussian model to data obtained in the three-tower experiment, uses a statistical parameter optimization method (see Yamartino et al. 1978). Similar problems were observed in attempting to explain the very wide range of concentrations associated with similar meteorological measurements. As noticed here in examining the vertical spread of the plume and the relatively low concentrations at the second and third tower distances, no significant differences between initial disperison volumes

TABLE 4

COMPARISON OF PREDICTED AND MONITORED PEAK CO CONCENTRATIONS (ppm)

Event No.	Peak CO Measured Concentration			Peak CO Predicted Concentrations		
	Tower 1	Tower 2	Tower 3	Tower 1	Tower 2	Tower 3
B707 Aircraft						
	Stability A					
67	8.1	1.1	2.5	6.07	2.58	1.56
123	2.2	3.0	2.1	9.58	1.58	0.96
	Stability B					
22	1.6	0.4	0.5	3.61	1.14	1.04
	Stability D					
1	2.6	0.5	0.[illegible]	8.71	3.65	3.91
18	3.1	2.5	1.5	7.91	3.15	2.62
19	3.9	2.1	1.[illegible]	7.41	3.95	3.05
69	0.6	0.[illegible]	0.6	6.65	2.51	2.08
85	2.1	2.1	1.1	2.05	3.29	0.71
89	1.4	0.2	0.5	9.01	6.01	2.22
90	1.9	0.8	0.4	10.54	6.68	5.15
102	3.7	1.5	1.7	9.85	5.92	3.96
105	1.6	1.1	0.5	7.10	0.58	2.59
109	1.8	1.5	2.1	10.32	9.24	4.21
148	3.9	2.2	1.[illegible]	14.71	9.51	4.90
132	1.1	1.9	0.3	6.59	2.71	0.95
139	2.2	2.5	0.4	7.85	5.88	2.07
B727 Aircraft						
	Stability A					
110	0.6	0.2	0.2	5.67	1.27	0.81
	Stability D					
25	0.9	0.4	0.[illegible]	0.55	0.82	1.01
31	0.5	0.5	0.2	14.08	1.20	1.26
101	0.5	1.0	0.9	9.96	9.15	5.81
127	0.6	0.[illegible]	0.[illegible]	16.20	10.02	6.52

and subsequent dispersion rates could be found between aircraft types because of the range of variability in the measurements. All of the analyses completed to date indicate that further work is necessary in order to successfully distinguish between the effects of the initial rapid dispersion in the turbulent jet wake, and the slower rates of dispersion normally associated with ambient turbulence augmented by the entrainment effects of buoyant plume rise. It is anticipated that the availability of more detailed measurement data bases will also make the application of numerical modeling methods, such as the Egan-Mahoney EGAMA (Egan and Mahoney 1972) numerical advection-diffusion model, productive for future modeling efforts.

5. SUMMARY AND CONCLUSIONS

This paper has briefly reviewed the status of airport air quality modeling and the importance of the validation of models with the detailed measurement of concentration profiles and the associated meteorology. In addition to identifying the airport air quality models available and listing their basic features, the current deficiencies in the validation status of existing models have been mentioned. At short distances from aircraft sources, interactions of the several scales of turbulence and velocity field make the validity of several assumptions of the common Gaussian form of model questionable. At larger distances (> 1 mile), on the other hand, the current inadequacies are not likely to be as important for many applications, since Gaussian models generally give conservatively high predictions; and thus predictions of acceptable concentration levels are not likely to result in violation of National Ambient Air Quality Standards.

Gaussian models are currently the best validated of the basic transport models available for evaluating impact of airport operations beyond the airport property. Site-specific differences in source geometry or flow and turbulent dispersion characteristics generally make model "calibration," (rather than "validation") advisable for a new site. Expert advice should be solicited, however, when questions about concentrations on a finer scale or near flow obstacles are important, or when the transport and transformation of photochemical species is of interest.

Preliminary results of airport pollution monitoring programs at Dulles Airport have been used to examine validity of a plume rise estimation formula, and to investigate the best means for determining the initial volume occupied by aircraft exhaust within a few seconds of its emission from jet aircraft engines. The first plume rise formula evaluated produced noticeable improvement in the ability of the ERT-QIL model to simulate mean vertical pollutant profiles for all three aircraft types examined (B707, B727, and Concorde). Observed concentration versus distance relationships and variations in plume rise were not adequately explained by either previous or current analysis methods. The variability in estimated plume rise and vertical dispersion rates derived for both B707 and B727 aircraft suggest continued investigation is required. The use of numerical dispersion modeling methods would appear to be both feasible and productive now that more detailed measurement data bases have acquired in the three series of tower experiments at Dulles Airport.

6. REFERENCES

Briggs, G. A. 1976. Estimation of Downwash Effects, Power Generation: Air Pollution Monitoring and Control. K. E. Noll, ed., Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan.

Delany, B. T. 1977. Aircraft Vortex Effects on Ground-Level Pollutant Concentration and Tracking of Vortex Movement in the Airport Environment, presented at the Conference on Aircraft Wake Vortices, Cambridge, Mass., March 15-17, 1977.

Egan, B. A. and J. R. Mahoney 1972. Numerical Modeling of Advection and Diffusion of Urban Area Source Pollutants, J. Appl. Meteor. 11(2), pp. 312-322.

Haber, J. M. 1975: A Survey of Computer Models for Predicting Air Pollution from Airports, Tech. Rep. 75-1231-1, DOT FAA Report WI-75-1320-1.

Platt, M. et al. 1971. The Potential Impact of Aircraft Emissions Upon Air Quality, NREC, Report No. 1167-1, Northern Reserach Corporation.

Platt, Melvyn et al. 1973. Analysis of Air Quality at Airports, Report No. 1151-1, 2, and 3, Northern Research Engineering Corporation.

Record, F. A. et al. 1973. Airport Emission Inventory Program (AIRPLM) User Manual USEPA Contract Report 68-02-0041 T.O. #18.

Rote, D. et al. 1973. "Airport Vicinity Air Pollution Study," Report No. FAA-RD-73-115, December.

Rote, D. and L. Wangen 1975. "A Generalized Air Quality Assessment Model for Air Force Operations," Document No. AFWL-TR-74-304, February.

Smith, D. G. et al. 1977. Concorde Air Quality Monitoring and Analysis Program at Dulles International Airport. U.S. DOT Report No. FAA-AEQ-77-14.

Smith, D. G. 1978. Airport Air Quality Modeling - Recent Developments, Proceedings of the Spring Technical Meeting of the Northeast Atlantic International Section of the Air Pollution Control Association, Wakefield, Massachusetts, April 6, 1978.

Smith, D. G. 1978. Turbulent Dispersion around a Building in the Natural Wind and Effluent Reentry, Sc.D. Thesis, Harvard School of Public Health, Boston, Massachusetts.

Thayer, S. et al., 1973. Model Verification -- Aircraft Emissions Impact on Air Quality, Volume I, GEOMET Report No. EF-262.

Turner, D. 1970. Workbook of Atmospheric Dispersion Estimates, Environmental Protection Agency, Office of Air Program, Research Triangle Park, North Carolina, EPA No. AP-26.

Yamartino, R. J. 1977. A Preliminary Analysis of Jet Aircraft Plume Rise, Energy and Environmental Systems Division, Argonne National Laboratory Report, unpublished.

Yamartino, R. J. et al. 1978. Analysis of Plume Rise from Jet Aircraft, to be presented at the American Meteorological Society Symposium on Atmospheric Turbulence, Diffusion and Air Pollution, Reno, Nevada, January 1979 (in preparation).

DISCUSSION

LEACH: I would like to comment on the disparity between the Concorde dose and the subsonic dose. There is no possibility whatsoever that the Concorde measurements are underestimated. The Concorde measurements by Rolls Royce are probably as accurate as anything that has been done for aircraft, and the disparity must be completely due to plume rise and possibly plume temperature.

TAYLOR: We in fact have two different sets of emissions data for the Concorde. One was from Rolls Royce. Do you know where the other one came from, the original Concorde data?

D. SMITH: No.

PANEL DISCUSSION

WHERE DO WE GO FROM HERE?

Moderator: John E. Wesler
Federal Aviation Administration

Members: G. D. Kittredge
Environmental Protection Agency

D. M. Rote
University of Chicago

P. S. Daley
U. S. Air Force

PANEL DISCUSSION

WHERE DO WE GO FROM HERE?

Moderator: John E. Wesler
Federal Aviation Administration

Panel Members: George D. Kittredge
Environmental Protection Agency

Donald M. Rote
University of Chicago

Peter S. Daley
U.S. Air Force

J. E. WESLER:

The theme of this meeting has been to assess the state-of-the-art of predicting and analyzing the effect of aviation on air quality.

In the preceding sessions we have looked at the basic source of pollution from aviation-- the aircraft itself --the airport, and its influence on its environs, and we have shown some case studies that have tried to assess the environmental impact of airport pollution.

This afternoon's panel discussion will be more than a discussion among the panel members. Rather, it will be a conference discussion because we will solicit questions, comments, suggestions, and reactions from the audience.

First, each of the three daily chairmen will review or assess that part of the program over which he presided or any other parts that he would like to bring to our attention. Then we will be open to discussion from the floor, to questions and to comments.

G. D. KITTREDGE:

I would like to indicate generally what my own perspective is from inside EPA since EPA is a large bureaucracy and we all have different functions.

Unlike my two fellow panelists, I am not an authority or expert in the area of mathematical modeling or monitoring of air quality impact. Rather my viewpoint is that of the group within EPA charged with the responsibility for developing the regulations, assessing, taking the assessments of the impact and converting these into regulations (if the arguments support regulations), and dropping them if new arguments do not support regulations. I think of myself, and actually this includes my colleagues in Ann Arbor as well, as really more or less customers for the kinds of information which have been produced by the excellent series of papers which we have heard here.

With that bit of background, let me go over what I think I heard with respect to the three pollutant species which we are presently interested in controlling from aircraft operations.

With respect to hydrocarbons, the hydrocarbon-oxidant relationship seems to be about the same after hearing these papers as we perceived it to be when we distributed our Notice of Proposed Rulemaking in March. That is, we know within EPA that we have a serious oxidant problem. The problem of non-attainment, nationwide, of the photochemical oxidant standard is larger-looking to us than with respect to the other two pollutants. From this standpoint, regardless of what the specified detailed impact of aircraft finally amounts to, the pressure is on our agency to attempt to control all sources of hydrocarbon emissions in an effort to allay the broad oxidant problem, assuming that the costs of control are reasonable.

This is not to say that we would wish to discourage further efforts to put the hydrocarbon-emissions-oxidant relationship into better focus. Certainly this is highly desirable, but it appears to us that the need to control hydrocarbons is stronger than is the case for the other two pollutants.

More work certainly is indicated in the area of advanced mathematical models which can handle the photochemistry of atmospheric reactions.

Let's go on to carbon monoxide. Here we certainly perceive some uncertainties that we didn't perceive some six years ago. The current program, the monitoring program in which we will be participating with the FAA next month at the Washington National Airport, should help to shed further light on the need for controlling carbon monoxide from aircraft. Certainly the papers that have been presented here, the comments I have heard, do not indicate a strong case for this at this time. We, of course, can't reach a final determination in this area until we have gone through our complete rule-making process and have held the public hearings that most of you know we will be holding November 1 and 2 on the whole program of aircraft standards.

I was interested in Dr. Pasquill's comment the other day with respect to the utility of modeling for forecasting short-term events. Not being a mathematical modeler, I wonder to what extent this influences the evaluation of the information which we are getting in which CO contours, in terms of the one-hour standard and the eight-hour standard, are being developed through such techniques. How completely can we rely on such projections?

With respect to nitrogen oxides, as we said in the preamble, here we know we need a re-evaluation. The short-term NO_2 standard makes it further complicated. We are concerned that we treat the control of aircraft in a manner which is equitable and compatible with respect to the control of the other sources such as large stationary power-generation facilities, stationary gas turbines, which influence some of you as well as the aircraft gas turbines. We want to organize the overall program of standards such that the burden is reasonably equally distributed.

The practical fact is that we have about run out of controls with respect to automobiles. By the time the 1981 model year rolls around, automobiles are going to be down to NO_x emission levels about as low as they will ever be, so from there on the control is going to have to come from other sources.

It occurred to me this morning, in listening to the presentation describing the ORI work, that the way I have, at least informally, lined up the priorities from my perspective is exactly opposite to the trends that they forecast in terms of gross emissions; -- they projected, I believe, a decline in gross hydrocarbon emissions for airports going through the 1985 period as opposed to a rise in nitrogen oxides and carbon monoxide emissions. Nevertheless, we have to look at it from the standpoint of where the problem is with respect to attainment of all of the Ambient Air Quality Standards for the complete series of pollutants.

D. M. ROTE:

First off, I was very much impressed with the quality of the conference. I must confess that when I was asked to participate, I wondered whether we would merely rehash the old stuff over again, but I think that the information content of this conference was extremely good and I think that the presentation on the part of individuals was very good, very professional, and certainly a cut above a number of other conferences which I won't mention. I am very pleased to have been asked to participate in this activity.

In regard to some of the problems that were discussed, always at conferences where we have questions of scientific interest, the issues of importance are talked about, and at the end of the conference some one says we need more research. In some of the modeling work we did, we, of course, talked about the old problems of how do you estimate initial size of plumes, do you have plume rise, are there building wake effects?

I feel gratified that we actually did something about these problems this time. I think we have some new data; I think we have some new techniques that have been developed for obtaining new data; and I think we have new analysis techniques as a result of the Concorde study, the U.S. Air Force study at Williams, and the Boeing work with photographic methods. I think all of these methods -- if I have left something out, it is only because I have got a short memory and have forgotten the other things -- but I think the general impression is that new things are coming down the line and I think it looks very promising.

Of course, I would still say that we need more research.

As far as modeling capability and confidence are concerned, I think as a result of the programs that have been performed and are under way at the present time, that the modeling capability has definitely improved, and as far as I can see, there is reasonably general agreement with observations. I think the observations that are available indicate that we have some local problems, but that it is pretty difficult to see the airport contributions, if you get off the airport property and the models seem to confirm that idea. I think there are some local problems that need further addressing, but those are details which will, I am sure, come with time.

I was very impressed with the capabilities or at least the promising capabilities of photographic techniques. I think that the use of environmental shadows to improve the image intensity is an interesting thing which deserves further investigation.

I would also recommend trying this kind of experiment under much colder weather conditions where there are better chances of seeing a reasonable image. For example, you can go to O'Hare in essentially 10- or 20-degrees-below-zero-Fahrenheit weather, and I am sure you would have much better infrared images of the plume. You can see the plumes visually. I think it is worthwhile taking your camera the next time you go to O'Hare and exploring both infrared and visual photography. I think you might find you can do a lot better and enhance the data base somewhat.

I think also it might be worthwhile examining other than broadband IR optical methods, either by focusing attention on certain infrared bands associated with water vapor or perhaps associated with the black-body temperature range of the plume itself.

As far as particular pollutants are concerned, I think that CO has been reasonably, clearly demonstrated to be a local phenomenon around high-activity periods and high-activity zones. There are still some nagging problems which I don't feel too comfortable about. Some of the problems are specifically aircraft or airport associated.

That is a little hard to say, but I think there are both modeling and monitoring evidence that there may

very well be some violations of eight-hour standards around ramp areas, queuing areas, and automotive access roadways. Certainly the roadways and the ramp areas, because of their proximity to air intake ducts and consequent impact on internal building levels, may be worth considering. That problem hasn't been addressed at all at this conference.

As far as NO_x and hydrocarbons are concerned, I think they too are basically local and whether they are non-local or not depends to a certain extent upon what the final short-term NO_2 standards will be. I think we have reason not to dismiss the NO_2 problem. I think it may need to be looked at a little bit more, especially near the boundaries of the airports.

Hydrocarbons, of course, there is no health-based standard for hydrocarbons. But, looking at the guidelines, it looks as though, if there is a problem that could be exacerbated by additional hydrocarbons in a basin area or something like that, you might want to examine the airport hydrocarbons along with all the other sources of hydrocarbons that happen to be in the basin. We shouldn't put the finger on airports, but we shouldn't exclude them either unless as a result of some kind of risk analysis we find -- let's control those things which we can control best without sacrificing human safety. I think that aspect ought to be analyzed.

Now let me turn to those things which we have not addressed and which we probably ought to have addressed. This is not intended in any way to be criticism of this particular program or of its organizers. After all, one does what one can in the limited time. The problem of airports is one of perception. There are at least four or five perceptions that I can think of -- smell, which gives rise to odors; sight, which gives rise to clearly visible aerosols present in the atmosphere over airports; hearing, which certainly gives rise to sounds and is not part of this project, and, I suppose, the sense of touch.

I haven't figured out how to put that last one in as not too many people get hit by airplanes, but certainly the question of odors has not been discussed at all, nor has the question of visibility reduction been addressed.

I am eminently an expert on both these problems as I live not too far from O'Hare. I consider myself to be no more of an expert really than any citizen who happens to be exposed to airports. One very clearly can see the airport because of the aerosol accumulation. One can smell the airport because of the odors. Therefore there remains the question not so much are these things health hazards as are they reasons for causing the public to finger the airport as a source of problems. For that reason, those kind of questions ought to be addressed. Not because we are faced with litigation, but because we are faced with people ringing up the telephone and pounding on the doors continuously.

I have heard discussion in the past that there is the possibility, for example, to mask odors. I don't know what the upshot of that work is. It has been going on for several years. It would be nice to hear that subject addressed at a future workshop. It would also be nice to hear the question of who is responsible for the odors. Are these particular modes of aircraft activity, are they even aircraft activity at all?

I am sure that there is a certain amount of culpability on the part of aircraft and certainly one can smell an airport some distance away. In terms of perceptibility of airports, certainly the smell must range rather high. For example, if you drive on a major expressway to, again my old favorite, O'Hare, you can smell it about two miles before you get to it. You very definitely have an off-the-airport effect.

I believe that one can treat the odor problem by a method very similar to what we have already used on the CO and the NO_x problems. I can cite at least two studies that have been conducted on industrial odor problems in which they have essentially used the same kind of modeling techniques and calibrated the model output to odor level on the basis of complaints.

Now, of course, in the case of industrial odors, the complaint levels are often rather severe because the odors are probably much more perceptible and much easier to finger than airport odors would be. I think that it is probably worthwhile investigating odor complaints as a function of distance away from airports and doing some modeling calculations. Let's see if we can't quantify that problem and take it out of the realm of highly subjective perceptions.

I don't know what to say about the sight question unless one can find some way to reduce substantially the aerosol concentrations. I am not sure what can be done about it. I think certainly the use of the new combustion chambers that were introduced a few years ago has significantly improved that situation. Maybe the only way one can improve it further is by considering the various mitigating strategies in terms of ground activity of airplanes.

Unfortunately, we have not addressed that problem at all, nor have we really attempted to compute in fact what the change in visibility is around airports. I think that is something that ought to be addressed in the future. In conclusion, I think that a lot of the problems deal more with perception and we have not dealt with the perception problems as much as we, in fact, could and probably should.

P. S. DALEY:

First of all, I would like to second Don's and George's comments on the quality of the papers and the quality of the conference. I think we have made progress. I would like to take a tack on my comments similar to George Kittredge's and look at the pollutants one at a time.

For completeness, I will just make a couple of statements on particulate matter. I certainly concur

with Don that particulate matter is generally not a problem from turbine engines with the exception of the visibility problem around airports. The combustion work that has been done has apparently eliminated that problem.

With regard to CO, the studies do indicate generally low CO levels in and around the airport. However, there are problems in the vicinity of the buildings and the terminals, and the joint EPA/FAA study at Washington National should address that problem and get a better perspective on it.

My own observation is that the CO problem from automobiles on the passenger-loading side and arrival and departure side is probably on the same order as the problem from aircraft on the other side of the terminal, and it would be interesting to see if we can get this resolved.

The problem of modeling this particular pollution source in and around the terminal is extremely difficult because of the geometry and the very special conditions involved.

With regard to CO, it is also interesting to note the comment that was made earlier in the conference that CO emissions from airports are approximately less than one percent of the total emitted CO in the United States.

Hydrocarbons, again looking at it in the context of general emissions made by all sources of hydrocarbons in any air quality control region, are generally small as we saw this morning from the GRI data that was presented.

They are generally between one and three percent of the emissions in the immediate vicinity of the airport. We have to look at hydrocarbons in general on an air-quality-control-region or air-shed problem because it is basically the linking of the hydrocarbons to the oxidant problem that we are trying to get at. With regard to dispersion modeling, I don't think it is particularly applicable. Specifically, the modeling of the hydrocarbon problem in the vicinity of the airport is really not an appropriate way to look at hydrocarbons. In the absence of anybody doing that kind of thing here today, I guess the conclusion is that local concentrations of hydrocarbons are not a health problem as Dr. Kittredge pointed out.

Our own work on the hydrocarbons, as I pointed out on the first day of the conference, does indicate that there are benefits to be obtained in the hydrocarbon area, probably in comparison with benefits to be obtained on a cost basis from controlling other sources.

One of the more controversial items in view is the NO problem. NO is the primary constituent of NO_x emitted by turbine engines. This is not implicated as a health problem directly, but only after it forms NO_2, or reacts to form photochemical oxidants.

The speed of these reactions is in question. Some of the reactions of NO to form NO_2 apparently can take place quickly if we do have high concentrations of oxidants, particularly ozone, in the vicinity of the airport. The problem of whether the NO_x or just NO_2 is implicated as an important pollutant in the immediate airport vicinity, has been identified as being not clearly resolvable because we don't know the reaction rates. The NO_x itself is emitted as NO along the runway, which is remote to the terminal. The dispersion that takes place between the emission source and the receptors nearby, ultimately the people, and the time delay in converting NO to NO_2 by chemical reactions, seem to indicate that maybe NO_x control is not quite as important as some earlier work may have indicated.

I think this is what George Kittredge was alluding to when he said that NO_x was second place to hydrocarbons.

With regard to the Air Force, we are evaluating our emission control goals for all the emission factors, and we will be looking at the NO_x problem along that line.

Another important thing concerned with the NO_x problem, which hasn't been brought up, probably because we are not an engine design group, is that control of NO_x will probably compromise the control of hydrocarbons.

OPEN DISCUSSION

WESLER: Thank you, Peter. It strikes me in listening to the discussions here, and the papers over the past several days, that air quality modeling is probably in the same state today that noise modeling was perhaps five to ten years ago. We were addressing the same questions then of the noise emissions of various types of aircraft, and how to model the total impact around an airport based on the operations of those aircraft. Noise modeling perhaps has a slightly different residence time. It doesn't quite stockpile as much as air quality and therefore is somewhat simpler to model, but it is far more perceptible to people and they can seize upon it. I agree with Dr. Rote, noise perhaps, visible particulates, odors, may be seized upon by people who dislike an airport for reasons other than those. They are visible or perceptible results of the operation of those airports and therefore more immediately usable as a basis for complaints against the airport itself.

HELFRICH: I have an interesting question for you. At Washington National how many complaints do you get about odors and smoke and noise? Do you get many at all?

WESLER: I can't answer that directly, Bill. We have been keeping fairly good data on complaints about the Concorde both at Dulles and JFK airports. We have tried to keep track of the type of complaints in each case. Now, many of these complaints are about Concorde itself; many are about aircraft other than the Concorde.

It seems to me there are few if any complaints about odors. Visible particulates usually constitute about two percent. Noise is by far the largest category of complaints that we receive, and structural vibration is a second.

HELFRICH: I just wonder how much we have to worry about these complaints if they are only one percent of the total complaints?

WESLER: I think those complaints, and Dr. Rote can follow up on this, probably are site specific. At those airports that have residential areas immediately adjacent to the boundaries, particularly run-up areas and so forth, Boston comes immediately to mind, odor may be far more a complaint cause than at other airports. I think probably it is site specific.

YATES: As I gather from what has been said here, the airports seem to contribute very little to the overall air pollution around the area. Secondly, I think the study that EPA did last May, something like that, at the request of the neighborhood people around O'Hare, they came out exclusively and said their problem is not O'Hare. Their problem is the trucks and the cars and the freeways and the toll-ways around there.

Third, we take all complaints from people, regarding noise, whatever. I have yet to get one complaint on odor or smoke. We probably average about 1200 a year on noise. We also take them from all the other airports in the region and I have yet to find one in that.

I have the same question the gentleman before me had, and I think about Dr. Pasquill's comment yesterday, just how far to go with this thing and what is the need for it?

ROTE: I don't know why but for some reason or other I guess I am the focus of all these complaints. Somehow people seek me out and have heard that I have done a study and I suppose because they are against airports they seek out all kinds of obscure references to anybody who has done anything about airports. I suppose if they couldn't find me they would find somebody else. People go through all that trouble and then say they have a problem with odors around, for example, O'Hare Airport. I will speak of that because that is the one I have personal experience with. That leads me to believe that there is a problem and there may be other people out there who are complaining about it.

If I am wrong, that is fine. I am perfectly willing to accept that and if everybody in this room feels that there are no complaints about odor except the ones that I have heard, I am willing to throw that away.

KITTREDGE: I might add just one more comment there. We don't have any organized complaint assimilating center in this area. I would say that roughly perhaps one complaint related to odor or fuel spills comes in a year, to put it in perspective, and it is usually someone who is complaining primarily about fuel being dumped, perhaps during takeoff and landing operations, and complaining about odor as a secondary thing.

NASA at Lewis Research Center did a study on odor. They used a test cell and a trained human panel system developed by Arthur D. Little roughly three or four years ago. If I remember correctly, they felt they were successful in isolating the source of the odor to hydrocarbons, in other words, to unburned fuel around the ramp areas of the airport. I don't know of any study that takes the next step, to model or figure out how these odorous materials disseminate throughout the airport environment and how they impact on people.

I feel if it is true that the odors are associated with hydrocarbons, improvements to combustor design have to help unless, of course, the odors are largely the result of spilled fuel during refueling operations and that kind of thing.

TAYLOR: My experience with Logan airport has been that the people nearby are concerned about the odor. I went to a community meeting two weeks ago and I checked, at Jeffries Point, which is the nearest community to the southeast side of the terminal, and their primary concern was noise, but they were very concerned with odor and they are interested in the EIP that the Massport people issue. They do want some modeling of odors and they want a determination of which pollutants are causing these odors and breaking them down on a gas chromatograph, which hydrocarbons, what the concentrations are, and why the people are running into that problem. They were willing to spend money on it.

WESLER: I think perhaps odor is a matter of priorities. We have attacked the most important problems and appear at last to be getting them in hand. Another level of problem begins to arise, and I suspect odor is probably that third level of problem. It would be nice if we had the luxury of attacking the third and fourth and fifth problems instead of the first and second ones.

DALEY: Along that line, Don commented that the odor and the noise and the sight problems are the things we see and impact on us directly. That doesn't unfortunately eliminate the problem of hydrocarbon control and oxidants. These are things the average individual in the community is not at all aware of. He can't see or feel or touch them, but that doesn't mean that we as professionals in the pollution field can ignore them or even put them down one notch.

WESLER: Complaints are a very poor measure of the impact of these environmental effects on people. They can perceive an impact such as noise or visible particulates but that doesn't necessarily mean these are the most important by any means.

TAYLOR: As I see this hydrocarbon problem in the Canadian situation, the only reason we are at the present time not addressing it and not measuring it and not modeling it is that we don't have standards.

Not necessarily because it has been proven to be a problem or not. We don't really have a health standard. Hydrocarbons have such a wide range of molecular weights from one carbon to the other. I don't know the highest volatile one, probably 10 or 12, and I think the reason we are not measuring it is not because we know it isn't the problem, but we don't have a handle on a standard we can compare it to.

The Department of Transport policy is that we will not measure something for which there are no national ambient air quality objectives because we are not primarily interested in making research reports. We are trying to prove that our activities are within standards or are not within standards. We are waiting. We almost have to wait for the States to come up with the regulation, and modify it to our environment. We are waiting for a specification on that before we start making measurements.

All I am trying to say here is that we haven't really proven one way or the other. We know that hydrocarbons are going to be in the same concentration area as carbon monoxide, which is very low, in parts per million, and may or may not be a problem.

GELINAS: It appears to me that we haven't really addressed adequately the impact of airports on oxidant concentrations, expecially in those areas of the country where they are going to have a hard time meeting oxidant standards, for example, Los Angeles and various other cities. I think more efforts need to be made to better quantify what strategies for reducing hydrocarbon emissions at airports could help improve the situation of attaining the oxidant standards.

KITTREDGE: I certainly endorse that. The comment is in the same direction, I believe, as my own at the start of the session this afternoon, that we have so many oxidant non-attainment areas that we certainly have to consider hydrocarbon control as a serious strategy for any source which can be economically controlled, including aircraft.

AUSTIN: I would like to address the question of general aviation airports. It seems that all the papers that were read or discussed about the tests at general aviation airports concluded that they didn't contribute very much to the problem.

I am wondering if FAA or EPA is ready to say that to the field. I think it is important for two reasons. We could reduce the size of the environmental documents, if we could eliminate these five or ten pages at a GA airport. It would be good to use our resources better if we could put them into one of the other areas that we really have to look at.

KITTREDGE: Well, one of the key features of the notice of proposed rule making that we referred to several times is a proposal to eliminate the standards applicable to general aviation aircraft, and that is a direct consequence of several of the studies you heard reported here which tended to indicate that the impact was more minimal than we had thought six years ago.

As to whether this is finalized or not really depends on the hearings and our analysis of the comments and everything that goes with it but certainly that is our plan at this point.

WESLER: We would be reluctant to make any conclusions from that, though, for environmental impact assessments and other analyses that are required for grant funds, for example. Certainly the potential impact at GA airports will still have to be examined even though there may not be a need or a basis for regulating the emissions from the aircraft themselves. There is still the problem of the picture as a whole and its potential impact on its environs.

BOUBEL: I recall four or five years ago, when I was involved in the Environmental Impact Statement for expansion at Portland International Airport at a public hearing we heard a supposedly knowledgeable person make the statement that he knew the airport was violating carbon monoxide standards because he could see it at takeoff and could smell it all the time. When you get into public complaints, you really have to be able to break these down quite a bit and it may not be the airport they smell. It conceivably could be something else and the same way with visibility, so I would caution you on that.

I have one question or maybe it is a comment. If we do launch into a program for engine manufacturers and users, or change of cycles or modes, so that we get into more hydrocarbon control, less emissions from the aircraft, I think it is very possible we will increase NO_x emissions and it is also possible that we will even increase CO emissions, in some respect.

You can't just automatically say that reduction in hydrocarbon will give you a reduction in CO because there are different mechanisms involved. My concern is that if hydrocarbons are controlled but at the expense of increasing either CO or oxides of nitrogen, this might have an effect if it became public. It might tend to enter into some future rule making and tend to negate the hydrocarbon control methods that may be in the research stage.

KITTREDGE: Perhaps I can comment first. I am sure that others can add to this. Certainly we have to consider these tradeoffs in the rule making that we are going through now. As to the actual extent to which hydrocarbon control is compromised by control of the other species, I think it might be more appropriate for some of the engine representatives here with us today to comment on that point, but all I can say is that from EPA's standpoint, we must consider these tradeoffs and you are entirely right in pointing that out.

Perhaps Tony would like to add to that.

WASSELL: I would like to express my appreciation to the FAA for organizing this conference. I have found it interesting and informative, and I think it has given me personally a broader perspective and I have

a question for Mr. Kittredge. I will put mine first and come back to his comment.

I would like to know what bases EPA has used to formulate the proposed revision of its Code Emission Standards with their increasing severity that were published in March. We have heard in these last three days that on the basis of air quality predictions, we have got a number of inaccuracies in the predicting mechanisms. Dr. Pasquill pointed that out and it has been referred to by the panel. Nevertheless, it has been pointed out that there have been violations of the national ambient air quality standards on the airport itself in localized areas to which the public is without access. In general, the airports don't contribute to the surrounding areas and act as sinks rather than sources of pollution. The aircraft industry has consistently stated that if it has got to meet the letter of regulations as they are currently laid down, we probably haven't got the technology, and I would just like to see what Mr. Kittredge thinks is EPA's rationale for the regulations.

Before he answers, perhaps I will make a comment on the question he put to me or to the aircraft industry. It is indeed true, in trying to meet the standards as they are currently promulgated, taking note of the fact that we are not quite sure how compliance demonstrations should be met, but assuming some method of compliance has to be adopted, then certainly we are finding that tradeoffs between hydrocarbons and carbon monoxides and smoke and oxides are becoming very important in the development of combustion systems aimed at meeting the regulations. I think it is a very timely comment that we should perhaps take more note of the interactions of the pollutants before setting all the standards.

KITTREDGE: Tony, your question is an awkward one, which I expect you may realize. This is not a public hearing and I can't say anything here that in any way can prejudice what is going to come out of the complete rule-making action, as a part of which we will certainly be considering additional comments furnished by persons such as yourself that bear on these very points.

The rule-making action that we proposed in March, as you know, is in most respects a relaxation of the original standards which would have gone into effect in January of next year, primarily as a result of our conviction that the technology just wasn't ready, and secondarily as we got into the program, because of our growing awareness that the air quality homework needed to be redone.

The information that we put together roughly this time last year, which is in the NPRM, was based on what we knew at that time. We now have considerably more information and we will be considering it before final promulgation and I think that is about as far as I can go along those lines.

WESLER: In George's defense although he doesn't need one, both he and we of the FAA sometimes find ourselves in the awkward position, where rule making is underway, of not being able to debate some of these points in public.

GELINAS: Mr. Kittredge, I have a question for you. Would the expansion of the existing airports with emissions greater than a hundred tons per year which are located in non-attainment areas, require an emission offset for those additional pollutants?

KITTREDGE: I am not very familiar with our offset program, but I think it would, yes.

GELINAS: Do you have any idea of how these offsets might be attained?

KITTREDGE: No. We have been playing around with other sources of the same pollutants showing that, granted that hydrocarbon emissions are going to go up, you could squeeze the emissions down from perhaps a petroleum refinery or some other source in the same area.

GELINAS: Most of these areas are going to require reasonable further progress towards attaining the standards. The emission rates in the whole region must be decreased in the future years out to 1982 and 1987. I was curious if you knew ways in which they could attain offsets. I see that with the expansion of airports in the future. Another question is what does an expansion of the airport entail? Would that be a new satellite area or new gate or an expansion of the number of operations at a given airport? Would that entail requirements of offset?

KITTREDGE: What level of change it would take to require an offset I honestly don't know. I am not at all close to that.

GELINAS: I guess that would have to be related back to the amount of emissions that would be increased accordingly.

KITTREDGE: As to hydrocarbon emissions, the other logical sources to work with are automobiles, and since the vehicles are being squeezed already, what you have to work with is inspection and maintenance or curtailment of new highway projects perhaps as a tradeoff with the airport and you have stationary sources such as dry cleaning plants and other manufacturing operations.

GELINAS: With industrial area facilities trying to grow as well, there is going to be a real challenge to try and get emission offsets. I guess I am trying to make a plug here for my paper. I was thinking that perhaps these operational control strategies, if some of them could be considered, that might be a way to attain an emission offset.

I don't know if you heard my paper this morning. I was trying to get your feeling on whether that might be an acceptable way that EPA would allow the extension of a given airport in an urban area.

KITTREDGE: I was late. I missed your paper. Certainly operations control would be a selling point that could be used in connection with such a project. We were very interested in the ground operations control of aircraft back when the

standards were first promulgated in 1973, and participated with the FAA and the ATA in some experiments at Atlanta with aircraft operations.

GELINAS: I guess that could even go as far as getting reduction in vapor control techniques for fueling of aircraft, storage tanks on the ground, that whole category there.

PASQUILL: I thought you might like me to reiterate my views on some aspects of dispersion science in light of vapors and discussions made since I gave my presentation. Before I do, I wonder if I might take ten seconds or so for a meteorological joke told to me and recalled by Don Rote's reference to the importance of perception.

Many years ago, the Meteorological Office in England was forced to undertake a series of experiments on rain making as I think many other organizations were likewise forced to do, and I was involved in the planning and execution of those experiments in the 1950's.

My experiment was concerned with trying to demonstrate whether or not ground-based silver-iodide generators, if used in advance of a warm frontal band of rain, would augment that rainfall. The experiment was set up with the release of the silver iodide near Salisbury on Salisbury Plain, in southwesterly winds. There were special arrangements for monitoring the rainfall in various areas to the east of that and around the London area. The press were apprised of these experiments from the beginning because it was of such public interest.

On the occasion of the first big release of silver iodide, in a warm frontal situation, there was a press reporter going around in London and it so happened that that warm front did produce a very large amount of rain. It really did pour down in London, and the reporter accosted a cab driver who was waiting with his cab and he said to him, "Did you know that this experiment was going on, and I wondered what you thought. Do you think that this rainfall that we are getting is caused by the silver iodide?" And the cab driver put his head out the window and let the rain stream down his face, smacked his lips and said, "Yes, I can taste it."

Well, I don't know whether this has a moral about perception.

When I was invited to come to this conference, one of my first thoughts was, well, is this going to be different from other air pollution conferences, of which we have many. I thought that from the dispersion meteorology point of view I could confidently expect that it would not be different, I mean in technical aspect, and I think this has proven to be correct.

I think that it is fair to say, and that it has come out of the discussion, that exactly the same problems that arise in this matter of dipersion modeling for airport sources have arisen in the other aspects of air pollution, in particular, one sees that one has exactly the same special difficulties, notably those arising from what goes on very close to the sources, and the difficulties that arise in attempting to predict or estimate what happens in individual events if one gets caught.

In other words, short-term concentrations at particular positions.

Exactly the same difficulties apply in your case of assessing the impact of airport pollution.

I think it is evident also from the papers and discussions that we have had that the use of detailed modeling doesn't necessarily and always, allow one to see the wood for the trees in assessing the effects, and as in the other applications of air pollution modeling, it is likewise clear that the concentration modeling stage may have entailed a misapplication of the basic dispersion parameters that I used in estimating the concentration.

We have noted one or two cases of that and I think that with that aspect in mind it is important that people who are concerned with one aspect or another of this modeling should be encouraged to do several things.

First, to take critical opinion on the meaningfulness, the applicability, of these dispersion parameters. This is quite easy to do. It is just a matter of communication.

Secondly, to undertake what I would call simplified calculations for selected cases. In many cases I think that it must be possible to make a useful estimate of what the impact, as you call it, has been, especially in the longer-term sense like the eight-hour sense from quite simple calculations where in the first instance one needn't worry about a detailed modeling of the spatial and temporal variations of releases.

A broad picture of the total amount of material would enable one to get a broad picture of the long-term eight-hour impact in many cases, which will be revealing, and one might, if one is doing calculations like that, focus one's interest more on the worst cases which I know some people have already been doing. I think one should do that more because in the end, and as we find in virtually all air pollution problems, it is the extreme cases that really produce the effects on the problems and not the general cases.

Then, I think that it would be very important to continue to press for crucial measurements of the type that establish the initial behavior of the releases at the source in these cases because then one is going to be in a very much better position to be realistic about the close-in impact of the release and its dispersion.

That can be done by visualization techniques. We have seen some of that, or indeed by the measurements of concentration distribution.

Then one should, of course, always be thinking of applying all these foregoing aspects in bringing out the uncertainty of model estimates. One hears talk of sensitivity studies, sensitivity to various parameters.

That is an essential part of it, but one has got to carry it further and have a notion of what the variations of parameters are going to be anyway as well as having evaluated what the sensitivity of the model is.

Finally, just one point about the odor problem; it appears at the moment that that is an aspect of evaluating the concentration distribution which is perhaps in practice not very pressing at the moment, but it is thought that well, one can't be sure that it won't be. All I can say is that if it is, then, of course, your modeling problem is just another order of mangitude greater because of the obvious fact that the odor problem is a matter then of instaneous concentrations and we all know how variable, enormously variable, instanteous concentrations are going to be.

SCHUERMAN: I am very much a neophyte in this whole issue. I have been involved for only about a year, but I did observe that we gave a lot of time to the modeling problem yesterday. It seemed to be a very strong theme. I suspect that these models are being used quite heavily to help us make decisions about the problem.

I don't know if my perspective is correct or not, but that is my impression, and I also have the fear that we may all have a low level of confidence in the models, particularly, the issue of exhaust plumes seemed to crop up so regularly yesterday in the dispersion problem.

My observation of the paper (I think it was by Dr. Cermak on the scale modeling that he had done of the city problems with smoke stacks and so forth) left me with the impression that he was a man who has a very good handle on the techniques as well as the shortcomings of this approach, but the problem that we are trying to model, in general, is very large scale. We talk of 80-foot towers and many feet and meters associated with the problem.

In practice it is difficult for us to get the measurements that we all want to confirm these things that we are modeling or maybe we should really say simulating. I think it might be wise to pursue the approaches of Dr. Cermak and we might be able to study the exhaust plume problem among other things, in better detail.

Number one, just to get some visualization of the problem. I think that is important.

I think it is possible that some measurements can be taken, and that maybe progress can be made at a much faster rate in dealing with the model problem if the experimental aspect of this problem can be brought into view with higher concentrations. I offer that as my observation.

NELSON: I would like to pursue this line of thinking a little further. In my observation of the papers that had been presented on modeling, it would appear to me that the variations are great and that generally the models used in the past have erred in the over-prediction direction. Since we are running the Argonne model as one of the prime models in determining whether standards are needed or not, I wonder whether some of these errors in the over-prediction method are planned to be incorporated and the scudies re-run, together with the validation using hard data from Washington National? Is that correct?

ROTE: I think that some of the things that Dr. Pasquill talked about have been incorporated already. He has brought up some additional remarks and I think he pointed out a problem with the use of distance-dependent versus time-dependent coefficients. That was discussed at length and I think that is going to be pursued further, but the effects that were present in some of the earlier models are not in the present model.

The earlier models used the dispersion coefficients directly from the Turner workbook, which were three-minute sampling times, and even that was not commonly known. I think there was some confusion over the years as to whether that was three minutes or ten minutes and even given that confusion, it was not clear to people who used models whether one should worry about that at all. We did modify those models according to whatever theory and experiment were available at the time, and made them correspond at least theoretically to one-hour sampling times instead of three-minute sampling times.

Unfortunately, there is not a whole lot of data dealing with that subject. In particular, the data of Harry Cramer is probably the most complete data that I am familiar with, unless Frank can think of some other ones, which looked at the method by which one can transform those dispersion coefficients into longer sampling times, and that was the basis upon which we did transform those coefficients.

I think there is still quite a fair uncertainty in precisely what is happening in the near field, as Dr. Pasquill pointed out, and I think certainly the suggestion to look at the wind tunnel is a very good one. I think that a combination of the wind tunnel studies along with the visualization studies would be extremely useful.

I think in fact if you do those two things together then you can develop a little better confidence in problems you might have with scaling in the wind tunnel case.

I think there are definitely problems in obeying the similarity requirements. You see, you have this problem with smoke stacks, and you are going to have a much more severe problem in the case of aircraft because the size of the aircraft is critical in determining the wakes and turbulence generated by the vehicle itself. Whereas you will have some uncertainties, if you do the wind tunnel experiments, I think combining that with the visualization studies, if they prove to be fruitful, would be an excellent way to go.

NELSON: How long would that take?

ROTE: I would say you could do that kind of study in about a year. If we can develop these visualization experiments, I think that we are talking probably of the order of maybe two or three people working for a year. I was looking for Jack Cermak, but he is apparently not here, and he could probably give you an estimate of what it would take to do the wind tunnel, but I would say offhand a year's worth of work. I don't know how many man-years would be involved in that, but I would imagine a couple of people working could handle that problem.

I think the most important thing is to settle on a few configurations, head wind or tail wind, such as we saw, and to get a reasonable understanding of what is going on there.

HELFRICH: I would like to ask if the Air Force is planning to change its emissions goals? The ones I am aware of now are for 1979 and 1981, which compares with the 1973 EPA emission regulation, and, of course, we are looking at a NPRM, with 81 and 84 dates. Secondly, the people in our Government Products Division would like to know whether the Air Force plans to regulate emissions for military transport engines in the 1980's?

DALEY: We are in the process of looking at the Air Force goals for emissions. Whether there will be changes or not, I can't tell you. We will have a much clearer picture of this in six months when the current look is ended.

With regard to transport aircraft in general, I am not really prepared to talk about that, but I believe the policy or the goal of the Air Force is to buy as many off-the-shelf engine versions in the future as they can, but other aircraft engines if they are not off-the-shelf will be directed towards the emission goals.

LINDENHOFEN: One gentleman asked Mr. Kittredge if the EPA emissions offset policy applied to a modification of an airport, and I was surprised that you indicated it probably did.

I looked at that closely in the Clean Air Act Amendment of 1977, and, of course, not being a lawyer, just reading it straightforward, it appeared to me it was specific for stationary sources, talking about point sources. Actually, I think an airport, a large area source, could be controlled or its environment estimated through the indirect source review process.

The emissions offset policy to this time I believe has been applied at three sources in the United States, and they were all point sources, the GM plant, close to Tinker Air Force Base, the Volkswagon plant up in Pennsylvania, and, the most recent one, I think that negotiations are going forward on is Standard Oil's port off-loading facility in Long Beach.

I believe we would run into a lot of difficulty if the emissions offset policy was applied to airports, large area sources.

KITTREDGE: You may well be entirely right. I have not made a detailed study of this and my impromptu response to the gentleman's comments was not based on having studied the question I had mentally construed, that is, an airport is a large area source of pollution, and as such might fall under it, but you may well be right.

SEGAL: I would like to direct this statement to Dr. Rote. Because of the infrequent occurrence of worst-case wind conditions (low wind speeds) and the nighttime occurrence of worst-case stability conditions, models are usually validated with measurements taken during the more convenient daytime hours and during the more frequent times of higher wind speeds.

How accurately can models predict worst-case conditions from a non-worst-case measurement base?

ROTE: I think that is always an easy question to answer. So long as you are convinced that we ought to improve the tools, then the easy answer is we go out and do more measurements so we have a basis for improving the tools. As to when to perform the experiments, if you want to go to the worst-case situations, then of course you have to expand the focus of your study.

I realize in the case of Concorde you were very limited by the fact that there were only two Concorde landings a day. You did the experiments when you had to do them. Obviously the fault with that particular experiment was that we had severe limitations on the range of meteorological conditions that we would work in. I suppose that it would be desirable to go back to some of these airports like Kennedy and LAX and do studies under more adverse meteorological conditions, and also adverse traffic conditions.

Since you are not only addressing annual average standards but also once-or-twice-per-year standards, then I suppose the time you ought to be out there doing measurements is the time when you expect to have those once-or-twice-a-year worst cases like around Christmas and Thanksgiving and Easter, and I will take all volunteers for those who want some field work at those times.

WESLER: As a plug for Howie Segal's paper, Monday afternoon he tried to do a worst-case condition for a general aviation airport down in Florida, and he did get a pretty bad case down there.

RIEHL: I would like to address a couple of topics, one concerning the wind tunnel. One of our conclusions with our studies with the infrared imaging was the fact that that problem was a good place to start, which we decided somehow to do, and I think after seeing Professor Cermak's work, that we will not reinvent the wheel, but talk a lot to him.

Another important issue that was addressed earlier was, in improving hydrocarbon and carbon monoxide, will we do so at the expense of maybe NO_x? I think some of the fixes so to speak, that we have seen concerning some of these

items would do that. They are directly related, but, more importantly, I think that things which aren't really being considered and should be are not only one pollutant with respect to another, but the fixes that you are thinking about for these. Are they reliable? How do they affect safety? Are they cost effective? Are they fuel effective and things like that, and I don't think these things have been properly addressed and I think they should be.

HUIE: Regarding the worst-case situations, how do you address those? As I understand it, that really is the goal, the purpose of the models. You are able to take measurements under a particular set of circumstances, and the function of a model is to extend these measurements to other circumstances, to allow you to project what will happen under certain meteorological conditions, to allow you to project what will happen when you increase the burden on the airport. The answer simply is that is why we have models, and that is why we have modelers.

I hope that is why we have chemists. I do have one further question about the reduction in hydrocarbons. One of the apparent problems now with automobiles is that although hydrocarbons are being reduced, apparently the only things that are being measured are hydrocarbons. Aldehydes, which are actually worse as far as oxygen creation and are worse particularly as far as odor creation is concerned, may be increased at the expense of these hydrocarbons.

As hydrocarbons are being reduced with new engines, are other things like aldehydes going up?

KITTREDGE: In the automotive case, the widespread use of catalytic converters to achieve hydrocarbon standards, has worked to the advantage of reducing aldehyde levels also. We have seen numerous measurements demonstrating that through hydrocarbon standards, we have automatically gotten control that we didn't have, of aldehydes, polynuclear aromatics, and the like.

With respect to the emissions from the advanced combustors that we expect to be used to meet hydrocarbon standards from aircraft turbojet engines, I know of no penalty in terms of aldehyde emissions. Again, I would encourage Mr. Wassell or Mr. Nelson to comment on that point further. I am not aware that there is a trade-off.

WASSELL: I don't think we have many measurements differentiating between aldehydes and hydrocarbons. When such information has been gathered in the past, if you reduce the hydrocarbons, you normally also reduce the aldehydes.

ROTE: In response to the gentleman from NBS, as to why we have models, I think that there is enough uncertainty, not only in the model, but what constitutes a worst case to warrant establishing a sufficient observation data base. Coming back to my old favorite, O'Hare, you can specify conditions. You can go out there, for example, and do some observations of what happens to aircraft activity under various conditions, but I have seen cases where aircraft are lined up along every single piece of available pavement on the airport, and that I would say was a traffic worst case.

Now, if I hadn't gone out there and put that observation down on paper, I would never have modeled it. I never even would have thought of it. I would have thought the whole thing was absolutely ridiculous, but nevertheless that happens. Therefore one must go out and do some measurements and I have no idea what the air quality concentrations are under those conditions.

I wish I could have had one of Howard Segal's Ecolyzers at the time I was there. It would have been a very interesting study. I don't recommend that we sit around all year waiting for that one episode to occur, but obviously before we can settle the question of worst case, we have to do some appropriately designed measurements.

FORNEY: So far as I know, John, I am not under any constraints of what I can say because I am not involved in pollution rule making.

The first thing I would like to say is to George. In that part of FAA that has got to enforce his rules on engines no one was more grateful than I that he proposed removing them from general aviation and delaying the dates from January 1, 1979 because we couldn't do it by those dates. We don't know how to now, so we are grateful for the extra time so we can learn how. The uncertainty in the instruments specified by EPA, the conditions under which we have to operate and measure them, and things of that nature, and the variability among engines, is such that today we would have an extremely difficult job enforcing any standards on gaseous emissions.

That is just a side comment to lead up to my impression of this conference, and there is one seed of doubt I would like to put in every modeler's mind that has been here today. Nothing has been said here about the quality of emissions data from engines. Now one gentleman this morning asked Bill Patten about how good his ground service cart data was and how good his APU data was. That is how good the engine data is.

We have data and the best data that is available is on new engines. The FAA has had one project trying to determine what happens when engines are used, but in that program, every time the airline did some significant maintenance action on the engine, it was dropped from the program and it was no longer measured.

One contractor, JT9D in the 747 program, started out with 23 engines. I think nine months later, 22 had been dropped out, so that doesn't give us much data on engines, on what happens to engines as they are operated.

Now, we do know that FAA oversees the maintenance programs of all the airlines, and they are all different. Each airline establishes its own maintenance program. They satisfy the FAA that it is a safe and airworthy program and it is approved and it does not have to be like any one else's,

and I can give you one example of the kinds of things that happen.

We know one airline that buys spare parts for its compressors that are one half of what another airline buys for engine compressor parts for that same engine. That means one airline is letting its compressors deteriorate and concentrating on keeping its hot section in good shape. I don't know to what extent I am getting too involved in this, but the compressor performance, the air flow through it, and the efficiency, all affect the combustor inlet conditions, all of which affect the emissions. We don't know what those things do and it is going to take us a long time to find out. In all these models they assume this good engine data and you predict what is going to happen in 1990? We are not going to be flying brand new engines between now and 1990 and the engines are not removed as frequently from airliners as they used to be.

New engines are modular and there may be a problem with the module and rather than remove a whole engine, you take a hot section off and put a new one on. We don't know what that does and there is just an awful lot of effort that has to be made before we really know what the emission output from an engine is. I just wanted to say this much to let you know that that number I have been hanging on to is not worth hanging on to.

There is one other thing. It is standard practice today in airline service to reduce thrust at takeoff. The EPA parameter is based on full rated takeoff thrust. That is not used all the time. There is a reduced thrust and it is up to 25 percent. That's the present number that is permitted. That means that the thrust is down, the fuel flow is down, the emission numbers are different and we don't know all these things yet. This is just to let you know that in addition to improving your models which I am convinced aren't any good either, you have convinced me of that.

I loved that one this morning. I think it was the young lady here showed measured slope and then all three of the models were at 90 degrees to it. I am not really trying to make fun of that. I agree with you, Dr. Rote, the models have improved. They are better today then they were, the first one you made.

ROTE: You have given me an idea for how to define the worst case. I think the next calculation we do we are going to take the envelope of all the maximum measurements that were ever performed on emissions and use that. Would that be all right?

FORNEY: For what?

ROTE: Worst case. The worst case would be when you just happen to hit an airport with all engines that are in pretty bad shape.

FORNEY: I wouldn't have any trouble with your studying that and trying to determine if it is the worst case, but don't make me tell the engine man he can't ship his engine. I have got to say he can't deliver an engine or he can and that is where my big problem is.

ROTE. I think, to be serious about it, I think that this is one more reason why it is necessary to do measurements and to do a reasonably large ensemble of measurements instead of just going out and then taking a measurement here and a measurement there. One has to have a lot of data. I should stress one of the things that Howard Segal has been pushing for, and that is looking at the individual events. I think there is value in doing that, but I think it is important to do -- the reason I think it is important to look at individual events is because you can see them, you can pick them out of the background without any trouble, but by the same token, you had better take a large number of those single events to get a proper ensemble average.

As to how much of the variation from event to event is due to meteorology and how much is due to the emission question that you raised, I don't have the vaguest notion. But I am sure what you are saying is that one could account for factors of two and three in variance because of emissions alone, and I certainly agree with that.

WESLER: Thank you, Ken. I think you have a practical point there that sometimes we become so enamored of the mathematical aspect of these simulations that we forget that garbage in leads to garbage out.

MARTONE: -- the last couple of days I had a chance to talk with Jim Elwood from Pratt & Whitney. We are trying to put together a session on aircraft emissions for the '79 APCA meeting in Cincinatti. Tentatively, it looks as if we are going to have three papers which deal with variability in aircraft engine emissions. Jim has agreed to put together a paper on new JT9D engines.

However, he also mentioned that he is soliciting a paper from the Natural Gas Turbine Establishment, which I think will be on older engines. Don Bahr may put together a paper based on some variability results he has obtained at GE, so we may have a lot of answers to questions about variability of engines.

WESLER: That sounds very good. We have been making some measurements within the FAA, too. One is a program to which Ken referred.

I would like to thank George Kittredge, Dr. Don Rote, and Major Peter Daley for participating in the panel this afternoon and all of you for participating in the discussions.

AIR QUALITY & AVIATION: AN INTERNATIONAL CONFERENCE - LIST OF PARTICIPANTS

Richard L. Altman
Pratt & Whitney Aircraft
1125 - 15th Street, N.W.
Washington, D.C. 20005

Mary M. Anderson, Associate Administrator
for Policy and International Aviation Affairs
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D.C. 20591

N. Robert Arthur
204 Mowbray Road
Silver Spring, Maryland 20904

Frank Austin
Federal Aviation Admin.
Alaskan Region - AAL-4
632 West 6th Avenue
Anchorage, Alaska 99504

Dale F. Backman
F.A.A. Northwest Region
Chief, Appraisal and Planning Staff, ANW-8
FAA Bldg., Boeing Field
Seattle, Washington 98108

Donald W. Bahr
General Electric Co. M/D H-52
Aircraft Engine Group
Cincinnati, Ohio 45215

Graham J. Bailey
Counsellor (Transport)
Embassy of Australia
1601 Massachusetts Avenue, N.W.
Washington, D.C. 20036

E. M. Ballenzweig, AAE-10
Federal Aviation Administration
800 Independence Ave., S.W.
Washington, D.C. 20591

James S. Bauchspies
ORI, Inc.
1400 Spring Street
Silver Spring, Maryland 20910

Ernest Bauer
Institute for Defense Analyses
400 Army-Navy Drive
Arlington, Virginia 22202

Ladislao Beza
Embassy of Czechoslovakia
3900 Linnean Avenue, N.W.
Washington, D.C. 20008

Alec T. Binding
Douglas Aircraft C.
3855 Lakewood Blvd., Mail Code 36-41
Long Beach, California 90846

Herman C. Bliss
F.A.A. - AWE - 600
P.O. Box 92007
World Way Postal Center
Los Angeles, California 90009

Richard W. Boubel
DET ADTCECC
Tyndall AFB, Florida 32403

David Braslau
David Braslau Assocs., Inc.
2829 University Avenue, S.E.
Suite 342
Minneapolis, Minnesota 55414

Allie W. Callan, Jr.
Aerospace Engineering Department
Auburn University
Auburn, Alabama 36830

Jack E. Cermak
Colorado State University
Fort Collins, Colorado 80523

R. H. Clinkscales
International Aviation Consultant
6808 Glenmont Street
Falls Church, Virginia 22042

John Connolly
U.S. Environmental Protection Agency
P.O. Box 15027
Las Vegas, Nevada 89114

Jonathan D. Cook
GEOMET Inc.
15 Firstfield Road
Gaithersburg, Maryland 20760

Ken H. Crumbly
NASA, MS 475
Langley Research Center
Hampton, Virginia 23665

Peter S. Daley
Det 1, ADTC/ECA
Tyndall AFB, Florida 32403

Bernard T. Delaney
Fred C. Hart Associates
527 Madison Avenue
New York, New York

Jean Delsey
Institut de Recherche des Transports
109 Ar. S. Allende
69500 Bron, France

Ramesh Desai
Federal Aviation Administration
Airports Division, AWE-600
15000 Aviation Blvd.
Hawthorne, California

LIST OF PARTICIPANTS

Currie S. Downie
National Science Foundation
2212 Wakefield Street
Alexandria, Virginia 22308

Wm. H. Duewer
Lawrence Livermore Laboratory
L-262
Livermore, California

Charles R. Eastwood
NASA, Code ETW-6
Washington, D.C. 20546

James H. Elwood
Pratt & Whitney Aircraft
400 Main Street
East Hartford, Connecticut 06108

Charles C. Erhard
Federal Aviation Administration
Washington National Airport
AMA-6

V.E. Ferry
Direction Generale de l'Aviation Civile
93rd du Mo tparnasse
75006 Paris, France

Jim Few
ARO, Inc.
Arnold Air Force Station, Tennessee

A.K. Forney
FAA, AFS-140
800 Independence Avenue, S.W.
Washington, D.C. 20591

Edward R. Frederick
c/o APCA
P.O. Box 2861
Pittsburgh, Pennsylvania 15230

Gary Gelinas
Pacific Environmental Services, Inc.
1930 - 14th Street
Santa Monica, California 90404

Perry Goldberg
PDWA, Mail Stop EB-2C
East Hartford, Connecticut

Guy Goodman
IATA
1000 Sherbrooke St. W.
Montreal, Que., Canada

Sydney J. Gordon
Northrop Services, Inc.
1293 East Patrick Lane
Las Vegas, Nevada 89119

Stanley J. Green
General Aviation Manufacturers Assoc.
1025 Connecticut Avenue, N.W.
Washington, D. C. 20036

Charles Greenberg
Boeing Company
M/S 73-07
P.O. Box 3707
Seattle, Washington 98124

Howard R. Hammond
P.O. Box 23646
Tampa, Florida 33623

George P. Hanley
General Motors Corp Environmental Staff
GM Technical Center SAS Building
Warren, Michigan 48090

Robert E. Hanson
Port Authority of New York & New Jersey
Aviation Planning, Room 64N
One World Trade Center
New York, New York 10048

Linda Hartz
CACI 1815 N. Fort Meyer Drive
Arlington, Virginia 22209

William E. Heifrich
Pratt & Whitney Aircraft Group
400 Main Street, ADM-BS
East Hartford, Connecticut

Brent K. Hodder
Boeing
Box 3707, M/S 73-07
Seattle, Washington

Leroy W. Householder
Engineer - Air Force
7313 Burroughs Lane
Falls Church, Virginia 22043

Robert E. Huie
National Bureau of Standards
Washington, D.C. 20234

Gary L. Jacks
Air Force Engineering Technology Office
AFETO/DEVP
Tyndall AFB, Florida 32401

F. Nowell Jones
UCLA
Dept. of Psychology
University of California
Los Angeles, California 90024

Bruce Jordan
Environmental Protection Agency
Office of Air Quality Planning & Standards
Research Triangle Park, North Carolina 27511

Jackie Kaneshiro
USAF/2nd Weather Squadron
4533 B. Reeves Place
Waldorf, Maryland 20601

Jim Kawecki
Biospherics
4928 Wyacanda Road
Rockville, Maryland 20852

LIST OF PARTICIPANTS

Dennis Keefer
University of Tennessee Space Institute
Tullahoma, Tennessee 37388

George D. Kittredge AW455
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Anthony F. Klarman
Navy Air Prop Cen
PE71: AFK
P.O. Box 7176
Trenton, New Jersey 08628

Malcolm K.W. Ko
Atmospheric & Environmental Research, Inc.
872 Massachusetts Avenue
Suite 2-9
Arlington, Massachusetts 02174

Robert Koch
GEOMET
15 Firstfield Road
Gaithersburg, Maryland 20760

Arnold G. Konheim
Civil Aeronautics Board
Chief, Environmental Affairs Division
Washington, D.C. 20428

Nick Krull, AEE-10
Federal Aviation Administration
800 Independence Ave., S.W.
Washington, D.C. 20591

Robert J. LaRocca
Washington ARPT. Dist. OFF.
900 South Washington Street
Falls Church, Virginia 22046

W.J. Laurence
FAA Southern Region
P.O. Box 20636 c/o ASO-214
Atlanta, Georgia 30320

John F. Leach
British Aerospace
No. 7 DO
Filton Bristol, England

Herbert E. Lee
U.S. Army R&D Command
USA AVRADCOM
ATTN: DRDAV-BP (H.E. Lee)
P.O. Box 209
St. Louis, Missouri 63166

Eugene L. Lehr
Office of Environment & Safety, P-20
Department of Transportation
Washington, D.C. 20590

Harry Lindenhofen
Air National Guard
12301 Cedarwood Court
Woodbridge, Virginia 22191

R. J. Linn
American Airlines
633 Third Avenue
New York, New York 10017

Grady V. Maraman
Air Force Reserve
AFRESIDEFD
Robins AFB, Georgia 31098

Joseph A. Martone
Det 1 ADTC/ECC
Tyndall AFB, Florida 32403

Louis H. Mayo, Jr.
Airport Operators Council International
1700 K Street, N.W., Suite 602
Washington, D.C. 20006

John K. McGrath
FAA AFS-140
800 Independence Avenue, S.W.
Washington, D.C.

Larry Michalec
U.S. Navy
Code 64270 NARF
NAS, North Island
San Diego, California 92135

James T. Murphy
FAA, AAC 960
FAA Academy
Oklahoma City, Oklahoma

Dennis F. Naugle
USAF (Univ. of N. Carolina)
804 Christopher Road
Chapel Hill, North Carolina 27514

Arthur W. Nelson
Pratt & Whitney ACFT
400 Main Street, EB-2B
East Hartford, Connecticut 06108

David N. Netzer
Naval Postgraduate School
Monterey, California 93940

Buford H. Norris
FAA
P.O. Box 20636
Atlanta, Georgia 30320

Stanley K. Oleson
FAA
1739 So. Uinta Way
Denver, Colorado 80231

Flo Ormond, AEE-10
ORI, Inc.
800 Independence Ave., S.W.
Washington, D.C. 20591

James Ott
Aviation Week
425 National Press Bldg.
Washington, D.C. 20045

LIST OF PARTICIPANTS

Hans A. Panofsky
Penn State University
503 Walker Bldg
University Park, Pennsylvania 16802

Dr. F. Pasquill
37 Arbor Lane
Winnersh, Wokingham, Berks, England

C. William Patten
ORI, Inc.
1400 Spring Street
Silver Spring, Maryland 20910

Richard A. Porter
West Virginia University
Dept. of Civic Engineering
Morgantown, West Virginia 26806

Dr. John Powers, AEE-3
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D.C. 20591

John W. Reynolds, Jr.
FAA - AAP-410
Washington, D.C. 20591

Jerry A. Riehl
Boeing Commercial Airplane Company
MS 73-07
Seattle, Washington 98124

James Rogers, AEE-10
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D.C. 20591

Ernest S. Rosenberg, Chief
Regulatory Management
Office of Mobile Source Air Pollution Control
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Donald M. Rote
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, Illinois 60439

Lt. Col. Torsten Rothman
U.S. Air Force
H2 USAF/LEEV
Pentagon
Washington, D.C.

Robert W. Rummel
P.O. Box 7330
Mesa, Arizona 85206

Robert A. Samis
Landrum & Brown
290 Central Trust Bldg.
Cincinnati, Ohio 45202

Dick Sandys
P.O. Box 661
Menlo Park, California 94025

George J. Schewe
(NOAA) Environmental Protection Agency
MD-14
Research Triangle Park, North Carolina 27711

V. Allan Schuerman
Pratt & Whitney Aircraft
400 Main Street
East Hartford, Connecticut 06108

Howard Segal, AEE-10
Federal Aviation Administration
800 Independence Ave., S.W.
Washington D.C. 20591

Eugene Shelar
SRI International
333 Ravenswood Avenue
Menlo Park, California 94025

William E. Simpson
ORI, Inc.
1400 Spring Street
Silver Spring, Maryland 20910

Donald G. Smith
2054 North 14th Street
P.O. Box 827
Arlington, Virginia 22201

Douglas G. Smith
ERT
3 Militia Drive
Lexington, Massachusetts

Anthony F. Souza
Scott Environmental Technology, Inc.
Plusteadville, Pennsylvania 18949

Anthony P. Spera
FAA-Airport Planning - AEA 610
Federal Building
JFK International Airport
Jamaica, New York 11430

Alvin M Star
WAPORA, Inc.
211 East 43rd Street
New York, New York 10017

John Stockham
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

N. Sundararaman, AAE-10
Federal Aviation Administration
800 Independence Ave., S.W.
Washington, D.C. 20591

E. Jack Sweet
Avco Lycoming
550 South Main Street
Stratford, Connecticut

LIST OF PARTICIPANTS

Lawrence Taubenkibel
FAA, ARD 550
2100 Second Street, S.W.
Washington, D.C. 20591

Beth Taylor
ERT
3 Militia Drive
Lexington, Massachusetts

Len Taylor
Department of Transport, Canada
Place de Ville Tower C, Floor 20F/KFE
Ottawa, K1A ON8, Canada

T. W. Tesche
Systems Applications, Inc.
950 Northgate Drive
San Rafael, California 94903

William J. Toth
Society of Automotive Engineers
400 Commonwealth Drive
Warrendale, Pennsylvania 15096

George E. Umlauf
Systems Control, Inc.
1440 State College Blvd., Suite 6-A
Anaheim, California 92806

Harvey H. Van Wyen, AFS-102
FAA
800 Independence Ave., S.W.
Washington, D.C. 20591

J. M. Vaught
DDA Div General Motors
P.O. Box 894 Mail Code U27A
Indianapolis, Indiana 46206

Edward F. Versaw
Lockheed-California Co.
P.O. Box 551
Burbank, California 91520

A. B. Wassell
Rolls-Royce
P.O. Box 31
Derby, England

K. Watanabe
Japan Airlines
655 5th Avenue
New York, New York 10022

John Wesler, AEE-1,
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D.C. 20591

Air Commodore Sir Frank Whittle
Department of Aerospace Engineering
U.S. Naval Academy
Annapolis, Maryland

S. K. Wilson
Los Alamos Scientific Lab
P.O. Box 1663, MS 588
Los Alamos, New Mexico 87545

David Winer
FAA, AEE-110
800 Independence Avenue, S.W.
Washington, D.C. 20591

Robert Wise
United Technologies
400 Main Street
East Hartford, Connecticut 06108

Ken Yamamura
Pac. Missile Test Range
Code 32523
Point Muceu, California 93042

Robert J. Yamartino
Argonne National Laboratory
EES 12
Argonne, Illinois 60559

Louis H. Yates
FAA Great Lakes Region
Attn: Planning Staff, AGL-4
2300 East Devon Avenue
Des Plaines, Illinois 60018

AUTHOR INDEX